

**DESIGNING UBIQUITOUS COMPUTING FOR REFLECTION AND
LEARNING IN DIABETES MANAGEMENT**

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by

Lena Mamykina

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DESIGNING UBIQUITOUS COMPUTING FOR REFLECTION AND LEARNING IN DIABETES MANAGEMENT

Approved by:

Dr. Elizabeth Mynatt, Advisor
School of Interactive Computing
Georgia Institute of Technology

Dr. Nancy Nersessian
School of Interactive Computing
Georgia Institute of Technology

Dr. Gregory Abowd
School of Interactive Computing
Georgia Institute of Technology

Dr. Paul Dourish
Department of Informatics
Donald Bren School of Information
and Computer Sciences
University of California, Irvine

Dr. Amy Bruckman
School of Interactive Computing
Georgia Institute of Technology

Date Approved: March 31, 2009

To my husband and son.

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	v
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF SYMBOLS AND ABBREVIATIONS	xi
SUMMARY	xii
<u>CHAPTER</u>	
1 INTRODUCTION	3
CHAP: Personal Reflection for Individuals with Types 2 Diabetes	10
MAHI: Reflective Coaching in Diabetes Management	12
Di-Tag: Community Engagement in Reflection for Individuals with Type 2 Diabetes	14
Thesis Statement and Claims	15
Contributions	17
Research Overview	17
2 NOTES ON METHODOLOGY	19
Frameworks and Theories	19
Probes	20
Design-Based Research	22
3 BACKGROUND AND RELATED WORK	25
Diabetes and Diabetes Management	25
Reflection and Learning	27
Related work in Computing	34

4	CHAP: EXPLORATIONS IN COMPUTING FOR DIABETES MANAGEMENT	45
	Introduction	45
	Three Approaches to Investigation	50
	Discussion	63
	Opportunities for Future Research	69
	Conclusion	73
5	MAHI: REFLECTION IN SOCIAL SETTINGS	77
	Introduction	77
	Background	81
	MAHI Design	86
	MAHI Deployment Study	89
	Study Results	91
	General Discussion	102
6	ANALYSIS OF REFLECTION WITH MAHI: EXPLAINING THE IMPACT	105
	Introduction	105
	Background	108
	Qualitative Analysis	110
	Learning with MAHI	115
	Comparison with Control Group	131
	Cognitive Apprenticeship in Ubicomp	133
	Conclusions	136
7	DI-TAG: REFLECTION IN A COMMUNITY OF INDIVIDUALS WITH DIABETES	141
	Introduction	141
	Background	143

Studying Diabetes Support Groups	150
Di-Tag	157
Conclusions	169
8 REFLECTION AND LEARNING IN DIABETES MANAGEMENT AND BEYOND	173
Introduction	173
Understanding Engagement	176
Supporting Learning through Engagement	179
Summary	210
9 OPPORTUNITIES FOR FUTURE RESEARCH	211
Extending the Framework	211
Socio-Technical Research in the Context of Chronic Disease Management	214
APPENDIX A: Health Locus of Control Questionnaire	222
APPENDIX B: Diabetes Quality of Life Questionnaire	225
APPENDIX C: Qualitative Analysis: The Final Coding Scheme	228
APPENDIX D: Design: MAHI Mobile	235
APPENDIX E: Design: MAHI Web	236
APPENDIX F: Design: Di-Tag Mobile	237
APPENDIX G: Design: Di-Tag Web	238
REFERENCES	241
VITA	250

LIST OF TABLES

	Page
Table 1: Measurable impact of ubicomp for reflection in diabetes.	17
Table 2: Emerging themes from diabetes interviews and observations.	58
Table 3: MAHI usage patterns.	93
Table 4: Participant activity levels	94
Table 5: Health Locus of Control	96
Table 6: Diabetes Quality of Life	97
Table 7: Diabetes Understanding questionnaire	98
Table 8: Diet goals achievement results	99
Table 9: Reported behavior change	99
Table 10: Categories of coding	115
Table 11: Stages of learning process	116

LIST OF FIGURES

	Page
Figure 1: Components of CHAP.	53
Figure 2: Participant at home.	54
Figure 3: Diabetes decision cycle.	66
Figure 4: Mobile components of MAHI.	88
Figure 5: MAHI website.	88
Figure 6: Number of records captured with MAHI.	93
Figure 7: Di-Tag screenshot: the tag cloud.	163
Figure 8: Fish’N’Steps.	219
Figure 9: Time Aura.	221
Figure 10: Selected screen shots of MAHI Mobile.	235
Figure 11: MAHI Web, researchers' view.	236
Figure 12: MAHI Web, participants' and care providers' view.	236
Figure 13: Di-Tag Mobile.	237
Figure 14: Di-Tag Web, intro screen.	238
Figure 15: Di-Tag Web, record details.	239
Figure 16: Di-Tag Web, intro screen.	239
Figure 17: Di-Tag Web, single tag view.	240

SUMMARY

In many areas of human enterprise, private as well as professional, individuals shape their actions and choices based on lessons learned from their past experiences. *Reflection* has a particular significance for individuals with chronic diseases, such as diabetes. Due to the high individual differences between cases, each affected individual must find the optimal combination of lifestyle alterations and medication through reflective analysis of personal diseases history. Computing technologies, specifically ubiquitous and pervasive computing, strive to assist individuals in this daunting task by helping them to record relevant experiences and analyze the captured records for trends and correlations. However, these applications often minimize individuals' involvement with data capture. Instead, they rely on sensor networks, biosensors, and other automated capture mechanisms. In this dissertation I argue that excluding individuals from the monitoring process often leads to their disengagement from learning. In contrast, engaging individuals in proactive capture of relevant data helps them adopt a proactive attitude towards learning and enrich their understanding of their disease. I propose that computing for reflection should promote individuals' *engagement* in reflection by exploiting breakdowns in individuals' routines or understanding, support *continuity* in thinking that leads to a systematic refinement of ideas, and support *articulation* of thoughts and understanding that helps to transform insights into knowledge. I support my claims with the empirical evidence gathered during the design and deployment of three ubiquitous computing applications that support reflection in diabetes management.

PART I: INTRODUCTION

CHAPTER 1

INTRODUCTION

In many areas of human enterprise, private as well as professional, individuals shape their actions and choices based on lessons learned from their past experiences. *Reflection* is an essential human activity; it is fundamental to people's ability to make sense of the world around them and learn. The importance of reflection is perhaps best captured by the words of George Santayana: "Those who cannot remember the past are condemned to repeat it" (1918). Reflection plays an important role in professional arenas as well as in private affairs. For example, Donald Schon (1983) noticed that reflective action forms the basis of many professional practices. Reflection is important not only for each individual, but also for society as a whole. Harold Garfinkel (1967) viewed reflection and rationalization of past actions and choices as bases of stable social structures and accountability of human action.

Despite their importance to human lives, reflection and contemplation, these integral components of independent and critical thinking do not come without a considerable effort. William T. Daly writes:

"The human foot was not built for ballet. Only with discipline, training and pain, can it endure the strain and produce beauty. The human mind was not built for independent thinking. Only with discipline, training and pain, can it endure the strain and produce knowledge" (Daly, 1995)

Indeed, researchers in cognitive and social sciences argue that the human brain was shaped by evolution primarily as a mechanism for rapid reaction to the often-dangerous world, rather than for contemplation.

Supporting cognition, and in particular reflection, is one of the most persistent yet elusive goals of computing technologies that can be traced back to at least the 1940s. In one of the earliest renditions of computer augmentation of reflection, the Memex (Bush,

1945), a computerized office desk helped scientists record their relevant experiences using video cameras and microphones and add them to the structured collection of scientific records available for examination at a later date. Importantly, Memex allocated its users a proactive role in capturing, annotating, and structuring the records, if only to compensate for the limited capabilities of computing technologies of the time. In the later decades, the idea of supporting reflection through capture of relevant information and experiences gave rise to an entire family of computing applications, generally referred to as “capture and access” systems (Abowd and Mynatt, 2000).

As computing technologies matured, the research community’s vision of the power and intelligence of computing became more ambitious. In one version of this new vision, computing often transformed from a machine for capturing, storing, and retrieving information on demand, to an intelligent assistant, able to predict and anticipate its users’ needs and requests before they are explicitly expressed. A significant leap in this direction occurred in the early 1990s when Mark Weiser (1991) introduced the notion of ubiquitous computing. Weiser observed that many other useful technologies—such as electric motors or written language—became so widely available and penetrated the fabric of human daily experiences so deeply that they became invisible in people’s minds. Drawing the analogy with these now invisible technologies, Weiser predicted that computing technologies are destined to disappear from people’s conscious mind as well and become a part of the invisible infrastructure that makes up the basis of human experiences. In his vision, *calm* and invisible computing relies on distributed sensor networks to maintain continuous awareness of its users’ actions and their context. Through powerful inference mechanisms, it provides necessary assistance when it is needed, and disappears from individuals’ attention when no longer required.

Weiser’s powerful vision gave rise to a rich agenda in technologies necessary to enable the desired level of computing pervasiveness. Physical size and power consumption of computing devices, wireless communications and networking protocols,

software mobility and self-configuration, security and privacy are all among technical challenges that ubiquitous computing presented to the research community (Chalmers *et al.*, 2006). At the same time, the vision of calm or invisible ubiquitous computing led many researchers to focus on enabling computing intelligence necessary to predict and anticipate users' needs and desires. Some of the general directions in these investigations include: context-sensitive computing, ambient/ubiquitous intelligence, and recording/tracking and monitoring (Rogers, 2006).

While the vision of calm ubiquitous computing continues to inspire the research community, in recent years, researchers started to question both its plausibility and its benefits. Two major criticisms of Weiser's notion of calm computing include writings of Bell and Dourish (2007) and Rogers (2006). Despite some important differences, both of these works agree in characterizing the original vision of calm computing as too narrow to account for the richness and "messiness" of human experiences and practices in the real world. They question the consequences of over-reliance on computing intelligence on humans' ability for independent judgment, creativity and their ability to learn. Both of these works propose to shift the attention of the research community from enhancing intelligence of computing to embracing creativity and intelligence of individuals who use the technologies.

These works re-conceptualize the notion of calm ubiquitous computing and present a new challenge to the ubicomp research community to outline the research and design space for technologies that promote individual *engagement*. Examples of ubicomp applications that embrace user engagement include playful learning environments, such as The Hunting of the Snark and Ambient Wood (Rogers *et al.*, 2006), provocative public installations such as Urban Trash (Paulos and Jenkins, 2005), and information displays for home usage such as Tableau Machine (Romero, *et al.*, 2006). All these applications create the sense of wonder and enchantment (Romero, *et al.*, 2006), and engage their users in playful explorations, thus encouraging curiosity and creativity.

In a way, the call for engaging computing sets the agenda for the research presented in this document. According to both Bell and Dourish (2007) and Rogers (2006), the way to expand the new vision of engaging computing is through studies of users' adoption and appropriation of ubiquitous computing technologies in specific contexts. In my work, I set to examine how computing technologies can help individuals become more thoughtful, reflect on their past experiences and draw lessons for their future choices in a specific domain of human activity—the management of chronic diseases, such as diabetes. In addition, my goal was to further scrutinize the idea of engagement, specifically as it applies to learning, and identify specific ways ubiquitous computing technologies can foster proactive and reflective engagement of their users. The conclusions and recommendations presented here are a result of observations of individual and collective appropriation of three ubiquitous computing applications that facilitate reflection in diabetes management.

The results of my investigations confirmed that at least in the context of health management, user engagement is an important and necessary component of individuals' learning experience. The three applications I describe here gradually reduced their reliance on automated data capture. For example, in my later prototypes, I replaced motion detection sensors I used for activity capture with techniques that required explicit input from the users to describe their activities, through taking pictures or recording voice notes. At the same time, the level of user engagement with the monitoring process gradually increased. For example, the later prototypes included features for annotating the captured data in freeform or structured ways, and discussing the captured records with others, experts or peers. The deployment studies demonstrated that the more engaged individuals were with the monitoring process, the more they benefited from it and the more they learned about their diabetes. The automated monitoring did lead to genuine discoveries, but because individuals were disconnected from the capture process, they

missed opportunities for learning that occurred throughout the day while the data was being collected. On the other hand, the applications that took a more engaged approach to monitoring fostered reflection in context of individuals' everyday actions, and led to a more systematic increase in understanding and the accumulation of new knowledge.

My investigations helped me to expand the concept of engagement, and suggest ways to design computing technologies that help individuals not only engage in reflection, but also sustain productive engagement that leads to a systematic increase in understanding. I propose that computing for reflection should promote individuals' *engagement* in reflection by exploiting breakdowns in individuals' routines or understanding, support *continuity* in thinking that leads to a systematic refinement of ideas, and support *articulation* of thoughts and understanding that helps to transform insights into knowledge. In a way, the ideas described here present an even further departure from the calm computing paradigm, as they advocate not only engagement but also effort—an inescapable component of successful learning.

The transition from calm computing to engaging and effortful computing is not simply a matter of rhetoric; it has a number of important consequences for human-centered computing disciplines and for the design of technologies that strive to facilitate learning and reflection. At the same time, I am not proposing a new class of ubiquitous computing that specifically focuses on supporting reflection and learning. The notion of calm computing became a basis and an intellectual platform for research in ubiquitous computing following its introduction. In the similar fashion, the concepts of engagement, continuity and articulation, if adopted and further developed by the research community, can inspire a new generation of ubiquitous computing technologies that consider learning and reflection as integral components of all human activities. These concepts can highlight new research opportunities, for example in enabling more immediate analysis of the newly captured records to further support reflection as part of action, support experimentation by allowing greater user control over system's features, and devising

ways for individuals to engage in a structured discourse grounded in the data captured with distributed sensor networks.

In a way the dichotomy between calm and engaging and effortful approaches to ubiquitous computing may be due to some long-standing controversies surrounding the notions of action and reflection. The concept of calm computing that enriches individuals' environment with cues on different levels of intrusiveness that affect and guide individuals' choices, sometimes without individual's conscious awareness, is most consistent with "situated action" (Suchman, 1987). In parallel with this view of action, Donald Schon (1982) introduced the concept of "reflection-in-action". In this view reflection happens spontaneously and almost intuitively, as part of action rather than as a separate activity, divorced from action. In contrast to this view, much of the literature in learning sciences (e.g., Green and Taber, 1978) advocates the view of reflection and learning as purposeful, focused and conscious processes that require effort.

In my work I take an integrative approach to this dichotomy. Rather than subscribing to either of these positions, I argue that both of them are valid and are in fact complementary, rather than mutually exclusive. If we adopt Schon's terminology, reflection-in-action allows individuals to quickly draw on their ready repository of previous experiences and professional vocabulary ready at one's fingertips, much as calm ubiquitous computing suggests. However, the development of this repository requires thoughtful contemplation and "mulling over" one's past actions and choices at a time when there is no pressing need for action. The work presented in this dissertation deals attempts to take this integrative view of reflection and propose computing tools that support different aspects of it.

According to Bell and Dourish, and Rogers, the way to define a new vision for the ubiquitous computing of tomorrow is through in-depth analysis of individuals' engagement with ubiquitous technologies of today. I focus my investigations on supporting learning in the context of diabetes management for the following reasons.

Diabetes management is a challenging undertaking that requires learning many new skills, from coordinating diet and exercise, to manipulating a variety of monitoring devices (Bodenheimer, 2002). Even more challenging is learning from one's own experiences and engaging in reflective analysis of one's actions. Due to the high individual variability of cases, each person with diabetes must repeatedly revise and refine their approaches to diabetes management based on his or her own history and experiences. To accomplish this, individuals with diabetes need to adopt a highly inquisitive and reflective mindset, paying close attention to patterns of change in their blood sugar values and investigating causes of these changes. In a way, individuals need to become "detectives" searching for clues to successful diabetes management in their past, or "scientists", generating and testing hypotheses regarding problematic or beneficial choices.

My research draws on several methodological traditions. Most importantly, it is grounded in the studies of socio-technical systems and in the view of technology as being co-constructed by its designers through production and its users through user adoption or non-adoption (Du Gay *et al.*, 1997). As a consequence, the empirical grounds for the conclusions presented here were gained through three cycles of design and deployment of computing applications that target reflection and learning in the context of diabetes management. Each of these applications was designed and deployed in the general spirit of cultural and technology probes (Gaver, 1999; Hutchinson *et al.*, 2003) and inspired by the Design-Based Research methodology (DBR, Barab and Squire, 2004). Consistently with DBR, my work combines a hypothesis-driven research methodology with a generative approach to theory development. In this document I will discuss the measurable impact of my prototypes on individuals' health attitudes and behaviors and describe the in-depth analysis of patterns of individuals' engagement with these applications, which helped me to formulate the design principles I discussed above.

The three computing systems I discuss in this dissertation were designed to examine reflection on different levels. The first application, CHAP (Continuous Health Awareness Program), looked at reflection from a cognitive perspective. The main focus of CHAP deployment studies was on the flow of information between the system and the individuals, and on individuals' cognitive processes. CHAP was designed as a relatively traditional health monitoring application with the goal to automate the capture of health-related data to the degree possible, and then present the captured data to the individuals to raise their awareness of emerging trends. While CHAP did help individuals make discoveries and learn new aspects of diabetes management, their learning was limited and fragmented. The second application, MAHI (Mobile Access to Health Information), took a broader approach, examining individuals' reflection as it happens in the context of their everyday lives, thus integrating cognitive and social components. This application allowed me to examine continuity in individuals' thinking and articulation of their opinions, and introduce a number of mechanisms for engaging individuals with the monitoring process. However, learning with MAHI happened in a supervised manner, through cognitive apprenticeship between individuals with diabetes and an educator. The last application, Di-Tag (Diabetes Tagging), took an even broader approach and examined reflection in the rich social context of real world social networks. In addition, it allowed me to further scrutinize articulation with limited oversight from experts. In the rest of this section, I present more details on the design trajectory of each application and discuss how each application informed my design explorations. I then present the thesis statement, contributions and the outline for the rest of this document.

CHAP: Personal Reflection for Individuals with Type 2 Diabetes

One of my first experiences of developing applications that facilitate reflection for individuals with diabetes was designed as an extension of the Digital Family Portrait (Mynatt *et al.*, 2001). Building upon the existing sensing infrastructure, my application,

CHAP combined automated capture mechanisms with diary-style self-reporting tools to help individuals with type 2 diabetes notice patterns of dependencies between their activities and blood sugar values (Mamykina *et al.*, 2006). As I mentioned earlier, the main focus of CHAP was on individuals' cognitive processes and their ability to engage with and reflect upon the collected data. To achieve this, the CHAP deployment study was designed to create a relatively controlled, if somewhat artificial, settings for reflection. I asked the participants to review and verbalize their reflection on the data collected during the day at the end of each day. This approach allowed me to observe individuals' reflective thinking. The Talk Aloud protocol is a common tool in studies of cognition that allows researchers a glimpse into individuals' thought processes (Ericsson & Simon, 1980).

CHAP's design embodied the new paradigm of engaging computing because it contributed to individuals' wonder and puzzlement, and prompted them to experiment. As a result, the participants of the deployment studies were able to generate and test hypotheses regarding correlations between their activities and blood sugar values. At the same time, it illustrated several opportunities to further enhance their reflection.

Most importantly, it showed the need to study reflection in real-world and in the context of individuals' daily activities, instead of isolating it for the benefit of the investigators. Most of the discoveries and questions the participants reported occurred at unpredictable moments throughout the day, whenever individuals encountered a puzzling situation, rather than at times when they were mulling over the data in front of the researchers. This finding brought to my attention the notion of breakdowns in individuals' understanding and the importance of moments of wonder and puzzlement as triggers for reflection.

In addition, the study highlighted the importance of cumulative and incremental approach to experimentation. While both of the participants engaged in spontaneous experiments, these experiments were fragmented and isolated.

The most striking finding of the CHAP's deployment was the need for articulation of ideas and for a structured discourse about an individual's discoveries. Most of the daily interviews with the participants followed a relatively stable pattern: when presented with the data collected during the day, the individuals engaged in a reflective monologue, which concluded with the inevitable question directed to the present researcher: "Can this be true?" The individual discovery did not seem to produce reliable knowledge for the participants. Instead, it produced hypotheses that required social validation or confirmation. This finding highlighted the need for scaffolding mechanisms that assist learning in social contexts.

I describe the design, implementation, and deployment studies of CHAP in Chapter 4.

MAHI: Reflective Coaching in Diabetes Management

Inspired by the findings of CHAP deployment studies, I approached the design of my second application with three general notions in mind. It was clear that MAHI needed to be able to support reflection in more authentic settings, as it happens in moments when individuals experience puzzlement and wonder and are open to analytically engage with situations. In addition, it needed to provide a better support for experimentation, for example by helping individuals to adopt a more systematic approach to keeping track of their experiments and their results. Finally, it needed to help individuals articulate, discuss and validate their findings and discoveries. This last point was especially important since MAHI was designed to function in the context of diabetes education, with the supervision of a teacher (Mamykina *et al.*, 2008).

To address these findings, I designed MAHI for a mobile phone as its main platform. This made MAHI available to individuals during authentic learning opportunities that occurred in context of their daily activities. My expectation was that one of the common sources of breakdowns in understanding would be puzzling blood

sugar readings. To capitalize on these opportunities, MAHI included a modified and reprogrammed Bluetooth attachment to a commercial blood glucose meter that allowed the MAHI phone to capture the blood glucose readings and incorporate them into a web-based display of the data captured with the application. In addition, I designed MAHI to include features for freeform capture of experiences through such flexible and rich media as voice notes and photographs. During the deployment studies I asked the participants to use these features to annotate their blood glucose readings and to capture records of anything relevant to their disease. In addition, the MAHI website allowed individuals to record comments and visually couple them with the data, and was designed to maintain a history of individuals' mulling over the data, thus promoting continuity in thinking. And finally, to address the need for articulation in social settings, MAHI allowed individuals to share their records with the educator and discuss them in a bulletin board style. MAHI's web-based display showed a user's data in a relatively simple format that linked together automatically captured data, annotations, reports of other sources of breakdowns and the conversations with their educator.

Most importantly, the deployment study demonstrated that MAHI helped individuals assume a more proactive attitude towards their health, indicated by their adoption of an internal locus of control and achievement of their individual diabetes management goals. The subsequent qualitative analysis of the patterns of users' interaction with the applications provided some insights as to the possible reasons for such positive impact.

This study confirmed the importance of authentic reflection triggered by puzzling situations or breakdowns: over 50% of all discussions captured with MAHI started with a record of a confusing blood sugar value, a description of a puzzling symptom, or a question that emerged while shopping, cooking, or ordering a meal at a restaurant. The study also showed that the annotation of new readings at the time of capture served as the first step to engaging individuals in reflection. In addition, the persistent record of data

visually coupled with annotations and comments provided individuals with a history of their interactions with the records, thus leading to more systematic experimentation and higher level of coherence and continuity in learning. Finally, it showed that the ability to annotate records and discuss them with experts helped individuals formulate and articulate their ideas about the captured data and the experiences it reflected. However, there remained opportunities for additional support, in particular regarding articulation. In MAHI, the diabetes educator, who was a part of the socio-technical system helped individuals formulate and articulate their ideas. A question remained, however, whether and how computing technology can help individuals structure their thoughts without an assistance from an expert.

I describe the design of MAHI and its deployment study in greater details in Chapters 5 and 6.

Di-Tag: Community Engagement in Reflection for Individuals with Type 2 Diabetes

MAHI's deployment study helped me to gain a better appreciation for the importance of learning in authentic settings when reflection is triggered by difficulties and challenges individuals experience in the course of their daily lives. In addition, it highlighted ways to preserve continuity in thinking and experimentation that can lead to systematic increase in understanding. Finally, it showed the importance of articulating ideas and opinions about the experiences and their impact on learning. However, the specifics of the actual setting of MAHI deployment—diabetes education classes—presented a barrier to generalizing the design principles I advocate here beyond that particular context. In addition, reliance on an expert as the sole source of social scaffolding and support for articulation of understanding has obvious limitations, because the experts may not always be available and their time is usually limited.

To further explore the issues of articulation and to move beyond the specific context of diabetes education classes, I designed Di-Tag to support learning and

reflection in the context of a community of practice. My main goal in designing Di-Tag was to further explore the issues of articulation of thoughts and ideas, an activity I believe to be critical to the formation of knowledge. I was specifically interested in harnessing the potential of Communities of Practice (Lave and Wenger, 1991) and peer-based networks in enabling such articulation without the extensive involvement of experts. In addition to data capture features similar to the ones used in MAHI, Di-Tag allowed its users to classify their records using tags—descriptive key words. To further support social discourse around the captured data, I created a wiki-like environment for Di-Tag users, where each newly created tag automatically created a new wiki-page that listed the records corresponding to the tag and prompted tag’s creators to describe their opinions on the captured items. Other individuals could then view the written entries and edit them to incorporate their own experiences.

The deployment study of Di-Tag showed that this application had several benefits. Access to records captured by the community of individuals exposed Di-Tag users to the experiences of others and helped them reassess their understanding of “normal” patterns of diabetes. The encouragement to use tags to describe captured records further promoted articulation. In addition, sorting and filtering by tags provided individuals with a structured way to access their own records. And finally, viewing tags created by others exposed the participants to the multiplicity of interpretations of diabetes experiences within the community and enriched their own understanding of the disease.

I describe the design, implementation and the deployment study of Di-Tag in Chapter 7.

Thesis Statement and Claims

The claims of my dissertation can be summarized in the following thesis statement:

In the context of diabetes management, ubiquitous computing applications can

*facilitate reflection and learning from past experiences by 1) initiating **engagement** with reflection by capturing and exploiting authentic learning opportunities when individuals experience breakdowns in understanding, 2) supporting **continuity** in thinking and experimentation by linking together discrete learning episodes and 3) assisting in the formulation and **articulation** of opinions about captured experiences. Combined, these features will help individuals to adopt a more proactive personal stance towards their health and disease and advance their diabetes management skills.*

This thesis statement includes two sets of claims. The first presents three general principles for ubiquitous computing applications for reflection and learning. These principles emerged in the course of my engagement with diabetes management as an activity and through the design and deployment of the three applications I described previously, CHAP, MAHI, and Di-Tag. Each of these applications utilized a somewhat different set of features that corresponded to my developing understanding of the role of computing in supporting reflection in diabetes management. The deployment studies of these applications allowed me to observe how individuals with diabetes engaged with technology, which features were successful, which presented challenges, and where there were unrealized opportunities for support. The principles I propose in this dissertation are a result of my analysis of both successes and limitations of the applications. To support these principles I will draw on my analysis of users' engagement with the applications.

The second set of claims focuses on the measurable impact of ubicomp applications for reflection in diabetes management, designed in accordance with the principles presented above. In particular, I argue that enhancing the ability of individuals to engage in reflective analysis of past experiences helps them adopt a more proactive stance towards their disease, and improve their diabetes management practices. The main research tools I use to support these claims are listed in the Table 1 below.

Outcome	Evidence	Measure
Proactive personal stance towards the disease	Adoption of the Internal Locus of Control	Internal Locus of Control Questionnaire
Achievement of positive changes in behavior	Achievement of personal diabetes management goals	Self reported achievement of diabetes management goals (diet)

Table 1: Measurable impact of ubicomp for reflection in diabetes.

Contributions

This work makes the following contributions:

1. Provides a socio-technical perspective on diabetes management that highlights challenges individuals face and opportunities to address them with computing technologies.
2. Describes design principles for ubiquitous computing applications that strive to facilitate reflection and learning.
3. Provides examples of design solutions that adhere to the three formulated principles in the context of diabetes management.
4. Presents the results of deployment studies of three ubicomp applications for reflection in diabetes management that illustrate how individuals with diabetes appropriate ubiquitous computing technologies.

Research Overview

In the rest of this document I will discuss my conclusions regarding the ways to support reflection in diabetes with computing technology and the empirical basis for these conclusions gathered during the deployment studies.

Chapter 2 presents my approach to research and my methodological alignment. In that chapter I hope to explain my choice of research activities and describe the theoretical

contribution I intend to make. Chapter 3 presents an overview of the main issues discussed in the rest of this document and related work from the social sciences and computing.

In Part II, I present the empirical basis for my conclusions, with Chapters 4 through 7 discussing the three computing artifacts that led to the principles I propose in this dissertation; CHAP (Chapter 4), MAHI (Chapter 5 and 6) and Di-Tag (Chapter 7). It is important to note, however, that the majority of the conclusions presented in this dissertation were formulated as a result of the design explorations and the deployment study of MAHI. Consequently, I allocate two chapters to the discussion of MAHI. I cover the description of MAHI design and evaluation of its effectiveness on individuals' diabetes management practices in Chapter 5, and will discuss the qualitative analysis of users' engagement with MAHI, which led to formulation of the principles I proposed in the thesis statement in Chapter 6. The other two applications discussed in this document, CHAP and Di-Tag significantly contributed to this work by providing initial insights (CHAP) and helping me structure space for future research (Di-Tag). However, the majority of this document will focus on MAHI.

In Part III, I discuss the principles for supporting reflection in greater detail. In Chapter 8, I introduce additional overview of theories that provided the foundation for the principles, discuss the principles themselves, and draw upon my combined experiences in designing applications for diabetes management, as well as upon other ubicomp applications for reflection outside of chronic disease management. Finally, in Chapter 9, I conclude with some potential directions for future research.

CHAPTER 2

NOTES ON METHODOLOGY

From the beginning of my Ph.D. journey I hoped to contribute theoretically to the body of knowledge in the Human-Computer Interaction and Human-Centered Computing. However, these research communities continue to question what constitutes a valid theoretical contribution. Consequently, I believe it is important that I explicitly describe my theoretical and methodological allegiances.

Frameworks and Theories

My research focuses on reflection, a complex phenomenon that unfolds in the real world in the context of individuals' lives in all their richness and messiness. Consequently, I intended my theoretical contributions to be closer in spirit with frameworks, rather than theories. Here is how Tweney formulates the distinction between frameworks and theories:

“I am proposing that we recognize a similar distinction between claims based on traditional scientific methods (called here theories) and claims that attempt to map the complexity of the real-world behavior (called here frameworks). A theory is an attempt to construct a model of the world that meets certain criteria of testability: it makes predictions, is potentially disconfirmable, and has interesting consequences. A framework is an attempt to reconstruct a model of the world that meets criteria other than testability as such. An adequate framework is one that is consistent with the details of the process, is interestingly related to our theories of the world, and reduces the apparent complexity of the real-world process in a way that permits anchoring the framework to the data. In effect, an adequate framework must allow us to see order amid chaos. Thus, a physicist can give us a precise theory for predicting the path of a feather moving in a vacuum, and a framework for

understanding the feather's path in air.” (Tweney, 1989)

I find this distinction between frameworks and theories to be insightful and appropriate for the fields of HCI and HCC, because both of these disciplines can operate on different levels of complexity. Investigations of novel interaction techniques may lend themselves more easily to laboratory experiments and could lead to generation of testable theories. Explorations of socio-technical systems, on the other hand, can only be conducted in authentic settings, and in the full complexity of the real world. In this context, testability may not be the most important criteria for theoretical contributions. In accordance with Tweney's criteria for frameworks, I will try to illustrate the consistency of my proposed conclusions and design principles with the details of the process they model by drawing on the data from the deployment studies; I will show how they relate to other theories (and frameworks); and will use these principles to at least partially reduce the complexity of reflection as it happens in the real world and in the context of individuals' daily activities. In turn, I hope that my conclusions will help to structure the space for future investigations for myself and other researchers in the field.

In my investigations of reflection for diabetes management, I took the approach of studying socio-technical systems in the authentic settings of the real world deployment. This approach is complicated by the fact that I studied the adoption of systems that I designed myself, however, there are other researchers in HCI and HCC who proposed solutions to this dilemma. In the next section I describe one such approach, probes.

Probes

In the past three decades, the focus on augmenting working environments led to the emergence of research methodologies inspired by ethnography and anthropology, such as ethnomethodology (Garfinkel, 1967). A related approach, cognitive ethnography (Hollan *et al.*, 2000), was applied to studies of human cognition as it occurs in the natural work settings.

In recent years, however, the research community has begun to examine the everyday lives of the individuals. This transition challenged the appropriateness of ethnography-oriented techniques for investigating domestic environments. Concerns regarding privacy and the sensitive nature of such settings render ethnographic observations problematic and often impossible. For the same reasons, the utility of cognitive ethnography for investigation of reasoning and reflection in domestic environments and everyday situations is uncertain.

The challenges of investigating domestic environments inspired the development of a new set of techniques, called cultural probes (Gaver, 1999). Cultural probes are carefully designed sets of provocative materials intended to inspire emotional responses from people that reveal motivational forces shaping individuals' lives. Technology probes (Fitton *et al.*, 2004, Hutchinson *et al.*, 2003) further extend the concept of cultural probes: they serve as instruments to investigate unknown environments and as initial prototypes of the applications.

Until now, the focus of cultural or technology probes was on highlighting individuals' cultural or social biases, attitudes and deep motivational forces that drive their behavior (a notable exception is the work of Hayes and others on designing technology probes to investigate challenges of care for children with autism (Hayes *et al.*, 2004)). However, similar techniques could be applied to the studies of individual cognition involved in individual decision-making in the context of diabetes management. Just as cultural and technology probes, cognitive probes highlight and facilitate the processes under investigation, namely reflective reasoning, and provoke responses from the individuals. To accomplish this, cognitive probes first engage individuals in reasoning by providing them access to the data that may impact their choices and decisions and then capturing individuals' interactions with this data.

Design-Based Research

Hypotheses-driven research and controlled experiments continue to play an important role in HCI and HCC. One common trajectory of research is to use previous work in one's chosen area to formulate a hypothesis regarding the impact of a computational intervention on certain aspects of an individual's life. In this approach, the actual computational artifact is designed to embody the proposed theoretical hypotheses and the subsequent deployment studies (or controlled experiments) are used to either support or reject the original claims. While this approach deviates from the more rigorous "hypotheses falsification" tradition proposed by Karl Popper (Popper, 1959), it has been, arguably, accepted as satisfying the criteria of scientific rigor and validity. I believe, however, that this hypothesis-driven approach can be too restrictive in explorations of socio-technical systems, as it requires one to impose a certain level of control over the deployment environment, and is sub-optimal if one desires to approach deployment of computational artifacts in an open-minded manner, allowing users generate a new meaning of these artifact through their appropriation. Consequently, in my deployment studies, I adopted an integrated approach that embraced the complexity and unpredictability of real world environments and situations while maintaining a certain level of theory building rigor. To achieve this, I draw upon a popular methodology in Learning Sciences, Design-Based Research (DBR, Barab and Squire, 2004). Proponents of DBR see their goals as both development of new theories of learning and development of practical tools that facilitate learning in very concrete educational settings. To accomplish this, DBR adopted four important research practices:

- Commitment to understanding of education in real world settings.
- Flexible approach to study design that allows for alterations to the variables in the course of the study.
- Embracing an active role for researchers participating in the educational process.

- Favoring a generative approach over disconfirmation of pre-selected hypotheses.

In my deployment studies I borrow from Technology Probes and DBR approaches in that:

- The computing artifacts serve as both a research tool to investigate individuals' reflective thinking about diabetes, and an intervention that facilitates this reflective thinking.
- The deployment studies are conducted in authentic situations with minimal intrusion from the researchers; at the same time, the researchers take on a proactive role in the education process (one of my co-investigators taught the diabetes education classes observed during the study).
- While I approached the studies with an initial set of hypotheses, I favor generative approach to theory development; in fact the richest findings of all the deployment studies I describe in this document were the ones least expected prior to the deployment.

CHAPTER 3

MOTIVATION, BACKGROUND AND RELATED WORK

Diabetes and Diabetes Management

The steady growth of the elderly population, evident in recent years, has placed an unprecedented demand on the health care system. Chronic diseases typical for aging individuals demand continuous care, well beyond the capacity of the traditional health care institutions (Bodenheimer, 2002). One such disease, diabetes mellitus, affects an estimated 20% of men and women over the age of 65 and may lead to such complications as blindness, end-stage renal disease, stroke, and coronary artery disease (National Diabetes Association Facts and Figures Sheet, 2006).

In recent years, the development of technologies that support individuals in managing their health has become a vibrant, yet challenging, research area. Many of the challenges researchers face are a result of significant transformations in doctor and patient attitudes towards health and health care and their perception of their respective roles. The dominating division of labor in modern health care allocates most care responsibilities to professionals and experts while patients are often assigned the role of disengaged recipients of professional services. However, recent changes in the demographics of industrialized nations, coupled with new advances in computing technologies is challenging this long-held arrangement and is allowing individuals to adopt increasingly proactive roles in caring for themselves and their loved ones. The first noteworthy transformation in health care practice described by Karen Knorr Cetina (Knorr Cetina, 1999) involved the rearrangement of health care from traditional family practice to professional service delivered in specialized medical centers. Emergence of the first professional clinics in Paris, in the late eighteenth century, introduced dramatic changes to the dynamics of patient-doctor relationships. No longer in

the comfort of their familiar environment, surrounded by family and friends, patients lost much of their former influence over their health and health care. Instead, they were isolated in sterile clinical centers, surrounded by a host of medical professionals who often used Latin to discuss patients' conditions and the selected treatment. Thus began doctors' ascent to the status of unquestionable experts and patient disengagement from their health and its management, common to the social landscape of the modern health care.

However, recent decades have witnessed a number of trends that challenged this arrangement. The increasing number of individuals affected by chronic diseases is stretching traditional health care beyond its capacity. Contributing to this increase, advances in modern medicine have transformed terminal diseases, such as cancer, into chronic diseases that need to be managed throughout an individual's lifespan (Bodenheimer *et al.*, 2002). The growing aging population further exacerbates this trend with common diseases of old age (e.g., diabetes and congestive heart failure). Consequently, many individuals with chronic diseases find an unfamiliar need to proactively engage in the care.

At the same time, advances in the fields of mobile and ubiquitous computing and bioinformatics provide new opportunities for monitoring individuals' conditions using sophisticated biosensors and activity monitoring sensors (Intille, 2003; Mihailidis, 2002). Many of these applications make use of advanced monitoring techniques, and view their users as protagonists and decision-makers, rather than passive subjects of monitoring (Morris *et al.*, 2004; Mynatt *et al.*, 2001). These trends, while still nascent, create a starting point for the next transformation of the social fabric of health care, potentially reshaping the contemporary roles and responsibilities of doctors and patients.

In my own work, I focus on building ubiquitous computing applications that assist individuals with diabetes in the management of their health. Diabetes places the main burden of care on the affected individuals and presents a number of opportunities for

supported self-care (Bodenheimer, 2002; Kaufman *et al.*, 2003; Mamykina *et al.*, 2006). Management of blood sugar levels requires significant alterations to one's lifestyle. Drastic individual differences demand that those affected rely on individual discovery as much as on advice from professionals. The chronic nature of the disease leads to individuals favoring educated negotiation of boundaries over adoption of a completely risk-free lifestyle. All these aspects of diabetes management make it a challenging disease and its management a complex process deserving careful consideration.

Reflection and Learning

Views on Reflection

John Dewey Reflective Thinking

The Oxford English Dictionary provides several definitions of reflection. One of them is concerned with the way of thinking: a serious thought or consideration (www.askoxford.com, Oxford English Dictionary online). Many schools of thought in philosophy and social sciences adopted this particular meaning of reflection as synonymous with thinking, or critical thinking. For example, John Dewey, the first to introduce the concept of reflective thinking, proposes the following definition:

“Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends constitutes reflective thought.” (Dewey, 1933)

In this definition, as in many others following this tradition, the emphasis is on the mode of thinking, rather than its object. According to Dewey, the main attributes of reflective thinking are: 1) it aims at a conclusion; and 2) it is consecutive, continuous and orderly.

“Reflection involves not simply a sequence of ideas but con-sequence – a consecutive

ordering in such a way that each determines the next as its proper outcome, while each outcome in turn leans back on or refers to its predecessors.” (Dewey, 1933)

Dewey defines the following phases of reflective thinking:

1. Suggestions, in which the mind leaps forward to a possible solution;
2. An intellectualization of the difficulty or perplexity that has been felt (directly experienced) into a problem to be solved, a question for which the answer must be sought;
3. The use of one suggestion after another as a leading idea, or hypothesis, to initiate and guide observation and other operations in collection of factual material;
4. The mental elaboration of the idea or supposition as an idea or supposition (reasoning, in the sense in which reasoning is a part, not the whole of inference); and
5. Testing the hypothesis by overt or imaginative action.

These phases highlight the critical properties of reflective thinking that I will return to in the following chapters of my dissertation. In this definition, reflection is a conscious, purposeful activity; it requires active engagement and effort from the individuals; it also requires that one agrees to sustain and protract the at times uncomfortable state of doubt questioning and testing the initial suppositions until sufficient evidence renders them reliable or forces one to reject them. Importantly, for Dewey, this state of doubt is the critical factor in triggering reflective thinking:

“Demand for the solution of a perplexity is the steady and guiding factor in the entire process of reflection.” (Dewey, 1933)

Another important aspect of reflective thinking that I return to later in this document is its reliance on observations or facts, in other words data. This notion, proposed before the age of computing, is at the heart of technologies for reflection: capture of facts or data that can refresh memories of past experiences is the backbone of

many current applications for reflection. However, Dewey proposes that the data alone is not sufficient to support reflective thinking; these data need to be combined with ideas, or interpretations, accounts and explanations, as well as plans for utilizing the data:

“Data (facts) and ideas (suggestions, possible solutions) thus form the two indispensable and correlative factors of all reflective activity.” (Dewey, 1933)

In regards to education and learning, Dewey contrasts learning through reflection and discovery with the traditional education of his time, which, arguably, remains a predominant model of education to this day. In this traditional education, learning is viewed as transfer of facts from the expert to the student, which, in Dewey’s view, deprives students of the opportunity to reach their own understanding of the subject. Many of these ideas resonated with my empirical observations of individuals with diabetes reflecting on their past experiences and impacted the conclusions I describe in this dissertation.

Donald Schon: Reflection-in-Action

Another influential work in this tradition is Schon’s “Reflective Practitioner” (Schon, 1983). It examines reflection that informs individuals’ everyday action as an integral part of such action. Schon discusses his view of reflective thinking in the context of his analysis of professions and professional practices. He presents a sharp criticism of the contemporary view of professional knowledge as rule-based, and professional learning as learning of the rules and principles that individuals would follow in the course of their professional life. From this criticism, Schon develops an argument between technical rationality, a problem-solving approach advocated by many science-based professions, and reflection-in-action, in which practitioners engage in reflective conversations with situations treating each as unique, and yet relying on the experience and expertise collected during their practice.

Schon views technical rationality as an intellectual descendent of the positivism, and, consequently, as approaching practical problem-solving as an extension of scientific problem solving: by generating hypotheses, and devising a crucial experiment that allows one to choose the best among the alternative hypotheses. In fact, in my initial studies of CHAP, highly influenced by the decision-making view of diabetes management, I specifically monitored individuals' generation and testing of hypotheses.

However, after observing professionals in action, Schon concluded that more often than not, these strict rules and principles give way to the less formal rules-of-thumb or local practices, which Schon refers to as tacit knowing-in-action. This knowledge is a result of individuals' reflective practice that builds up their arsenal of available tools and results of their prior applications.

Thus, Schon views reflection-in-action as a reflective conversation with the situation, and a practitioner as a "researcher in the practice context." The process of reflection-in-action helps practitioners deal with uniqueness of each situation they confront, while using the foundation of their prior experiences. According to Schon, reflection-in-action consists of three steps:

1. When faced with a problem, a practitioner re-frames the problem, restructuring the situation in a way that is solvable from the arsenal of his prior experiences.
2. The situation talks back, generating unexpected consequences due to its uniqueness.
3. The practitioner evaluates the results and consequences of reframing, whether intended or unintended, on their desirability.

Jean Lave: Everyday Cognition

Similar in spirit to Schon's analysis of professional practices is Jean Lave's study of individuals' everyday math (Lave, 1988). Her research focused on investigating the impact of math skills acquired in schools on individuals' ability to carry on mathematical

operations in such everyday activities as grocery shopping, cooking, or selling goods at street markets. In accord with Schon's view, Lave finds little correlation between individuals' performance on standard math tests and their ability to conduct complex mathematical operations in practical everyday tasks. Based on these observations Lave concludes that formalized rules learned in schools have little impact on simple everyday activities. Instead, individuals acquire the necessary situated and embodied skills as part of their experiences in reflective practice.

Summary

Schon presents reflection as an integral part of any human activity and argues against viewing reflection as separate from action. This position can be viewed as contrasting with the notion of reflection and critical thinking as purposeful activities that require mental effort and concentration. In his essay, "Beyond Critical Thinking", William T. Daly writes:

"The human foot was not built for ballet. Only with discipline, training and pain, can it endure the strain and produce beauty. The human mind was not built for independent thinking. Only with discipline, training and pain, can it endure the strain and produce knowledge." (Daly, 1995)

I believe, however, that these views are complementary. In Schon's reflection-in-action, individuals draw upon the repository of experiences condensed in one's professional vocabulary. While this vocabulary is often used during action and as part of action, its development can benefit from purposeful, concentrated reflection done somewhat separately from action. Consequently, in my work, I focused on designing tools that can help individuals analyze their past experiences and build a repository of such experiences that can inform future actions.

There are other definitions of the word reflection that are in closer relation with its origins: reflect comes from the Latin reflectere meaning "to bend back." This definition

brings to mind a more commonplace usage of the term reflection as one's image in the mirror. Combining the two definitions produces a concept of thinking critically about oneself.

For the purposes of my research, I use a similar definition of reflection, as ***critical examination of actions and experiences in one's past in order to achieve new understanding***. In this definition I highlight the purposeful nature of reflective thinking, and its focus on individuals' own experiences rather than more general sources of information and knowledge. In my research, reflection is more comparable with learning from one's past, rather than examining one's beliefs and worldview. In addition, while I subscribe to Schon's notion of reflection-in-action, I believe that individuals wishing to learn from their past experience can benefit from focused contemplation when it happens at natural moments in the flow of their actions.

Learning as a Social and Situated Activity

There are different ways people learn new skills and many views on what constitutes knowledge and how it is acquired. This work draws inspiration from the socio-cultural theory of learning, which views knowledge as deeply embedded in social and cultural context, and learning as part of humans' everyday practice. This position contrasts with the more traditional view of knowledge as abstract and de-contextualized, and learning as belonging in classrooms.

In the field of learning sciences similar notions of learning through experience and experimentation inspired one of the prominent theories of learning, constructionism espoused by Jean Piaget and Seymour Papert (Papert and Harel, 1991). The proponents of constructionism reject the notion of learning as a transfer of de-contextualized knowledge and as an individual activity. Instead, they propose learning, especially learning sciences, through open-ended and playful construction of public artifacts. In addition, they embrace the social nature of learning, a notion first proposed in the

writings of Lev Vygotsky (Zuboff, 1988; Vygotsky, 1978). Vygotsky distinguishes between the abilities of a student learning new skills on her own, and a greater sphere of abilities when this learning is conducted in social settings, with the appropriate scaffolding from more experienced others. Consequently, the role of teachers in constructionism is to provide the necessary scaffolding in the form of coaching, mentoring and managing students' activities. Agency and empowerment of learners is an important concept in constructionists' approach; the learners themselves choose what they want to construct and have a control over the construction process.

One of the better-known examples of such contextualized learning is apprenticeship. In traditional apprenticeships—such as in painting or sculpture—the experts or masters seldom explicitly explained their skills or approaches to the students. Instead, they enacted their skills, thus allowing a group of apprentices to learn through observation and imitation within a community of peers. Not surprisingly, traditional apprenticeships usually evolved around learning in arts and crafts, where rules and practices might be difficult to formulate. I draw my inspiration in these questions from the studies of Lave and Wenger (Lave and Wenger, 1991) and their notion of Communities of Practice and Legitimate Peripheral Participation (LPP).

Just as Schon argued that professional problem solving does not rely on application of formal rules, Lave and Wenger argue that acquisition of these skills is different in nature from formal schooling. Observations of a number of professional (e.g., butchers, tailors) and non-professional (e.g., Alcoholics Anonymous) communities of practice led the researchers to conclude that learning in these communities occurs through observation and imitation. They argue that knowledge in these communities is preserved by the core members, who mastered the necessary skills in the course of their careers. New members join these communities at the periphery, and engage in observation and imitation of masters, while often performing small and well-defined tasks. With time and

acquisition of new skills, novices move from the periphery closer to the center of the community until they in turn become masters and keepers of community's practices.

This notion of observation and imitation is not dissimilar to the one described by Schon. In the architecture workshop case-study he illustrates learning by imitation through a reflective dialog between a master architect and a student. In this dialog the teacher demonstrates the reflective thinking approach by talking the student through his way of transforming the problematic situation through application of prior experience. As the student follows the master in this process she begins to imitate him by reusing the concepts and language he introduced.

Apprenticeship as a model of learning inspired a number of attempts to develop educational programs that subscribe to the socio-cultural theory of learning. Two examples that have particular significance for my work are Cognitive Apprenticeship (Collins, Brown, and Newman, 1991) and Communities of Learners (Rogoff, 1996). Both of these models advocate learning as a transformation of participation in which both educators and students contribute support and direction in shared endeavors. I present a more detailed discussion of Cognitive Apprenticeship in Chapter 6.

In my work I draw upon these views of learning as a social and contextualized activity and introduce social scaffolding mechanisms into design of computing applications for reflection.

Related Work in Computing

Ubiquitous Computing

This research is grounded in the intellectual tradition of Ubiquitous Computing, a concept introduced by Mark Weiser in the early 1990s that inspired several decades of active research. In his 1991 article in *Scientific American* (Weiser, 1991), Weiser presented an inspirational vision of hundreds and thousands of computing devices deeply

embedded in the fabric of everyday life, unobtrusively yet persistently providing assistance and guidance by informing choices and actions. In this vision, the computing is comparable to other technologies that became so absorbed in people's everyday practices that they disappeared from individuals' conscious view and became invisible. One example of such technologies are electric motors. At the infancy of this technology, a large factory could have several motors. Now, simple home appliances can have dozens of motors each, yet these motors remain largely invisible to their users. Another example is written language. Without writing, from signs on streets, to newspapers, to novels, human life is hard to imagine, yet when one looks at a street sign, one notices the content of the message rather than the technology that used to convey it. In Weiser's view, computing technology will soon reach the same level of pervasiveness and ubiquity.

However, to achieve this vision, the main focus of computing technologies should center on calmness, their ability to harmoniously coexist with each other and with their users. Indeed, if people are to be surrounded by hundreds of computing devices, these devices must not continuously compete for their users' attention, or create disruptions. Weiser illustrates the workings of the new ubiquitous computing through a scenario of Sal's day, an effortless flow of activities smoothly transitioning from home to work, from personal to professional activities, always maintaining just the right level of awareness of what's going on in the world near and far. Perhaps due to this scenario, Weiser's vision of calm computing became extended and took the form of computing supporting "calm living", or living free of inefficiencies, unwelcome disruptions and unrealized opportunities.

In the recent years there appeared several critical views of Weiser's vision of calm ubiquitous computing, or, rather, of the ubicomp community that continues to draw inspiration from "yesterday's tomorrow" (Bell and Dourish, 2007). I discuss two of these critical perspectives below. Both of these views inspired and motivated my work and

many of the ideas presented in this dissertation reflect and parallel the notions advocated by these researchers.

Yvonne Rogers (2006) examines the notion of calm, intelligent computing that inspired research in technologies that attempt to anticipate users' needs. She describes three main directions for such research, context-aware computing, ambient/ubiquitous intelligence and recording/tracking and monitoring; of these three areas, the last one is the most relevant to this dissertation. Rogers argues that, after three decades of active research, the current state of ubiquitous computing is nowhere near Weiser's vision. A wide survey of current ubicomp technologies and applications lead her to conclude that Weiser's vision might have set too ambitious goals for computing technologies and may not be attainable in near (or even far) future. Instead of reaching for unrealistic goals and dreaming about technologies of the future, she suggests setting more attainable goals and focus on building technologies that support human practices as they exist today. One approach to the design of ubicomp technologies she proposes in this and other publications is by focusing on supporting playful learning. One of the example applications she uses to illustrate playful learning with technology is Hunting the Snark: a game that inspires exploration, experimentation and learning by taking advantage of ambiguity, puzzlement and wonder, concepts very similar to the notion of breakdowns I advocate here.

A similar view on the original platform of ubiquitous computing is presented by Bell and Dourish (2007). Based on their examination of near-ubiquitous computing technologies in Singapore and South Korea, they propose that perhaps the vision of ubiquitous computing has already been realized, but in a different form than was originally conceived. Both case studies of ubicomp they present demonstrate that computing became deeply integrated into everyday fabric of human lives. However, instead of calm and seamless experiences of the original vision of ubicomp, both of these cases show how computing can embrace the messiness of real world life and human

affairs: “Computing technologies are embedded in social structures and cultural scripts of many sorts; ubicomp technologies prove also to be sites of social engagement, generational conflict, domestic regulation, religious practice, state surveillance, civic protest, romantic encounters, office politics, artistic expression, and more.”

Classic Capture and Access Applications

The notion of computing technologies augmenting human intelligence goes beyond ubiquitous computing. Perhaps the first vision of computing technology supporting reflective thinking was presented by Vannevar Bush (1945) in his article “As we may think” published in *Scientific American*. In his article, Bush described a vision of computational augmentation of human memory—Memex. An office-desk-like environment allows its users to capture and store electronic versions of documents and artifacts for later access. In addition, various wearable technologies, such as cameras or Dictaphones, allow scientists to capture important activities, such as scientific experiments.

Similar vision with perhaps a greater emphasis on the social nature of knowledge was presented by Douglas Engelbart (1962) in his idea of “Collective IQ.” In Collective IQ problem-solving is viewed not as an individual but as a group activity; consequently the goal of technology is to allow individuals to not only capture but also share related experiences. The notion of problem-solving as a collaborative activity is explored in the design and deployment of Di-Tag, which views diabetes learning and management in the context of collaboration within a community of individuals.

Recently there emerged a number of computing, and specifically ubiquitous computing applications that support and facilitate reflective thinking. Abowd and Mynatt (2000) define one family of such applications under the term capture and access. Sellen (Sellen *et al.*, 2007) uses the term life-logging technologies to describe a related class of

applications that allows individuals to capture relevant experiences for review at a later date.

Generally capture and access or life-logging applications use a variety of naturalistic capture techniques, such as video, audio or sensor-based to record activities and their context and allow individuals to access the captured records at a later date. Many capture and access applications were built to support work-related or educational activities.

While the general vision for these applications remains consistent with the Memex ideas, the technologies for both capture of records and access to them transformed significantly allowing more data to be captured automatically and striving for access anytime anywhere. On the capture side, Sellen distinguishes between wearables, portables or augmented environments (Sellen *et al.*, 2007). From the access perspective, one of the main promises is that these technologies will augment individuals' memory of their own past. In fact, studies show that such applications do have potential for augmenting individuals' recollection and recognition of events in the recent past. Below are some representative examples of such applications:

- Forget-Me-Not (Lamming and Flynn, 1994) allowed individuals to monitor locations and persons they encounter as part of their work activities.
- Tivoli (Moran *et al.*, 1997) allowed groups of individuals to capture a variety of data around group meeting.
- Classroom 2000 (Brotherton *et al.*, 2001) was meant for use in educational settings and allowed professors and students to capture classroom experiences through recording of audio, video, lecture slides and lecturer's and students' notes.
- Personal Audio Loop (PAL, Hayes *et al.*, 2004) is a near-term audio recording system to support the recovery of interrupted conversations.

In the personal arena, Rhodes (2000) introduced Remembrance Agent, a wearable application that allows individuals to capture and access personal experiences through video and audio records. More recently, Sellen (Sellen *et al.*, 2007) investigated the ability of randomly or intentionally taken photo-records to enhance individuals' memory of past events.

One typical characteristic of capture and access applications is their reliance on relatively free-form capture. These applications focus less on automatically recognizing and discriminating particular activities of interest. Instead they use such naturalistic capture techniques as audio or video, allow the individuals to record a holistic view of the transpired event and leave it up to the users to pick out the moments of significance.

Health and Wellness Applications

Exploratory studies of individuals' health attitudes in the field of Human Computer Interaction have focused on a variety of health challenges and target user groups. For example, Mynatt *et al.* (2001) targeted "aging in place" and found that the transition to the assisted living was often initiated by the adult children who desired peace of mind regarding the well-being of their aging parents. Morris *et al.* (2004) focused their investigations on aging adults coping with cognitive decline and suggested a number of design directions to reinforce social connectedness of such individuals. In addition, there is a considerable body of research in the field of biomedical informatics documenting the difficulties lay people experience in comprehending medical information (Patel *et al.*, 2002) and making sense of their own data (Kaufman *et al.*, 2003).

The ability to automatically monitor individuals' health and activities became one of the necessary components of health-related or aging-related applications. However, the design, implementation and deployment of such systems remain a significant challenge. Many projects taking advantage of monitoring rely on "Wizard of Oz" techniques (Mynatt *et al.*, 2001), utilized relatively simple monitoring (Wagner and Grove, 2002), or

focused on comparatively well-defined and easily recognizable activities, such as medication taking (Fishkin, 2004). Recognizing more complex, but also more typical human activities remains non-trivial (Munguia *et al.*, 2004). In addition to the inherent computational complexities, such systems present considerable challenges for deployment and installation in domestic environments (Beckmann *et al.*, 2004). There are, however, some promising new developments. For example, Amft (Amft *et al.*, 2006) use acoustic analysis of chewing sounds for dietary monitoring. Using a small microphone inserted into an individual's ear, the researchers are able to reliably distinguish chewing sounds from other acoustic effects, such as speech. Chang (Chang *et al.*, 2006) use an augmented environment approach enriching a dining table surface with RFID sensors and weight sensors to monitor what and how much of the foods available on the table each individual consumes in the course of the meal. The feasibility studies of the augmented table surfaces show 80% accuracy, comparable to that of the traditional dietary assessment methods.

These new monitoring capabilities allowed researchers to propose a number of creative solutions in the home health care space. In some of these applications, automated capture techniques assist human observers, as is the case with monitoring of children with autism (Hayes *et al.*, 2004). Others, such as the Digital Family Portrait (Mynatt *et al.*, 2001) or the CareNet display (Consolvo and Towle, 2005) focus on supporting adult children in their care for the remote or collocated parents. Yet others target the aging individuals themselves. For example, Mihailidis (2002) proposed systems that provide cognitive assistance to aging individuals with dementia.

A somewhat different class of computing applications utilizes data captured by sensors to explicitly change individuals' health behavior. Intille (2003) argues that providing relevant information at the time of making decisions may influence individuals' health choices. Jafarinami (2005) utilizes persuasive computing techniques to maintain individuals' awareness of their posture. Further developing the idea of

computing persuasion, Fish'n'Steps (Lin *et al.*, 2006) attempts to promote higher levels of physical activities by mapping one's steps measured with a pedometer to the development of an animated character, a fish in a fish tank. Another application in this family (Consolvo *et al.*, 2006), uses social communication between friends to achieve the same goal – promote increased physical activity.

While these and many other explorations inspired and motivated my work, the research questions regarding disease self-management postulated at the beginning of this document remained unanswered. Examples of applications that focus on promoting reflection for lay individuals managing chronic diseases are not easy to come by. Much of the work in the novel capture techniques focuses almost entirely on the sensing side, with less attention to the access part of the equation. At the other side of the spectrum, applications that strive for behavior change tend to focus on the actual behaviors or readiness to change them, rather than on analytical and reflective skills of the individuals. The findings presented here extend the existing work in the field by focusing on the disease self-management strategies, health reasoning involved in the management, the limitations of the current practices and opportunities to address them with ubiquitous or pervasive computing applications.

PART II: AN EMPIRICAL BASIS FOR EXPLORING COMPUTING

MEDIATION OF REFLECTION

CHAPTER 4

CHAP: EXPLORATIONS IN COMPUTING FOR DIABETES MANAGEMENT

Introduction

My engagement with technologies for reflection in the context of diabetes management grew out of several consulting projects, which focused on work practices, patterns of information access and approaches to making decision of home health nurses. To gain a deeper understanding of the nature of nurses' work, I conducted an observational study of home health nurses as they delivered care to home-bound patients suffering from chronic diseases, such as diabetes, or recovering from acute ailments such as trauma or heart attack. The insights gathered during this study led me to propose an approach to visualizing patients' data that made trends and patterns more readily apparent (Mamykina *et al.*, 2004). However, these observations also showed that augmenting nurses' work with more sophisticated data entry and presentation techniques could not resolve underlying tensions due to the fragmented nature of care delivered by the nurses. The existing work practices and reimbursement policies only allow for infrequent interaction between the nurses and their patients. To address this limitation, many in the health care community see the need for the continuous uninterrupted health monitoring that records indicators of individuals' health in the context of their everyday lives and activities. The idea of the continuous health monitoring remains somewhat controversial in the health care community. On one hand, it shows a clear potential to recreate accurate patterns of development in patients' conditions, increase researchers' and clinicians' understanding of diseases, and lead to new approaches to treatment. On the other hand, in

the context of current clinical practices, increasing the amount of patient-related data will likely lead to the information overload of clinical professionals who are already overburdened and tend to be in short supply. One solution to this dilemma was to automate the analysis of the recorded data, and synthesize the data for review by clinicians. A complementary approach, which became the topic of my research presented here, was to focus on patients themselves as proactive agents in their own care. My goal became designing health monitoring applications that assist individuals in collecting, processing, analyzing and interpreting the collected data.

The first step in realizing this vision, development of capturing technologies capable of collecting the relevant data, such as sensor networks and biosensors, is a subject of intensive investigations. I present a more thorough review of emerging health monitoring technologies in Chapter 2; some representative examples include the works of Beckman *et al.* (2004) and Munguia *et al.* (2004). However, my early interactions with individuals who suffer from chronic diseases, and often tend to be of advanced age and lower socio-economic status, showed that these individuals might find it difficult to interpret the collected data and draw meaningful conclusions and insights from it. Other health monitoring applications allocated the data different roles, for example helping individuals to notice an impending crisis (a typical example of such technology is The Outpatient Health Monitoring System, <http://www.renci.org/focus-areas/project-archive/ohms>). However, the majority of the health monitoring applications I encountered while reviewing related work in this field, made an assumption that once the data is collected and presented to the individuals, they will draw appropriate inferences, without elaborating on the nature of such inferences.

In this first phase of my work, my goals were to re-examine assumptions inherent in the emerging health monitoring applications, and answer the following research questions:

- How do individuals with chronic diseases currently manage their health?
- How do they form judgments and reason regarding their health and diseases?
- In what ways can computing applications inform individuals' actions and assist them in managing their diseases?

Addressing these questions demanded application of mixed research methods. Qualitative interviews of individuals with diabetes and an observational study of the diabetes support group helped me gain rich insights into current diabetes management practices. To reveal health reasoning strategies, I worked with a team of students to create and deploy a technology probe, CHAP (Continuous Health Awareness Program)—a prototype of the application incorporating state-of-the-art monitoring techniques that engaged individuals in the reflective analysis of their disease.

These investigations revealed three main aspects of diabetes management; the first of these became the overarching theme for my dissertation work presented here:

- *The need to become a detective*: due to the considerable variability of cases, there is a need for individuals to proactively engage in the analysis of their disease.
- *Flexible negotiation of actions*: chronic nature of the disease leads to the individuals' desire to flexibly negotiate their actions based on the anticipated outcomes rather than to adopt a completely risk-free lifestyle.

- *Importance of motivation:* challenges of diabetes management often result in disengagement from the process and lead to astonishingly high levels of non-compliance with medical regimens or desired lifestyle change.

Individuals' ability to successfully manage diabetes largely depends on their understanding of the correlations between their daily activities and blood sugar levels. Because of the high individual differences between cases, each individual with diabetes must rely on their own ability to discern relevant and significant patterns by reflecting on their past activities and their impact on blood sugar values. Even decisions regarding the choice of treatment must rely on the same trial and error cycle. Each new adjustment to the prescribed combination of medications is assessed during regular 3 or 6-month doctor visits and modified until there is sufficient evidence that the optimal combination has been found.

The probe described in this chapter assisted individuals in this process, by helping them to keep track of their daily activities and compare them to the recorded changes in the blood sugar values. Since the main focus of my investigation was on individuals' information processing and reasoning, CHAP deployment study was designed to expose these process as individuals engaged with the data, and make them available to analysis.

The deployment study showed that CHAP helped users actively engage in reflection. Having the opportunity to review a consolidated record of activities and blood sugar values revealed many puzzles that needed explanation. Why was my blood sugar this high after this type of breakfast? Why did it drop so quickly after this type of exercise? These were some representative questions that study participants faced.

The study showed that to answer these questions the participants generated hypotheses and tested them through experiments, varying different properties of their activities and observing the impact of these activities on blood sugar levels. In a way, their thinking was not unlike the process of scientific discovery (Nersessian, 1992). The high-density records of blood sugar values, combined with records of daily activities, provided the necessary material for evaluating hypotheses and in-depth analysis of suspected correlations.

At the same time, the study revealed a number of limitations in reasoning and experimentation inspired by CHAP. The artificial setting for reflection, which happened at a specified time of day and in presence of the researchers, was helpful in illuminating individuals' approaches to reasoning. However, it created a gap between actions and reflection on these actions. Most of the discoveries reported by the participants happened in the course of their daily activities and were triggered by confusing symptoms, puzzling blood sugar values, or questions regarding the optimal choice of action. This observation brought to my attention the importance of *authentic learning opportunities* that arise when individuals try to resolve puzzling situations and seek answers to questions they face in their daily lives. At the same time, it showed a number of limitations in individuals' learning and experimentation. Due to the lack of tools for more systematic planning and execution of experiments, these experiments were fragmented and, at times, redundant. In addition, the study showed that while individuals did make genuine discoveries, their confidence in these discoveries remained low throughout the study. The participants continued to seek social validation and confirmation of their findings, rather than rely on data as empirical evidence.

In the rest of this chapter I discuss my three approaches to investigation and the findings they generated in greater detail.

Three Approaches to Investigation

Interviews

To gain a deeper understanding of diabetes as a disease and diabetes management practices from the perspective of affected individuals, I conducted interviews of 15 individuals with diabetes. The participants of the interviews varied in age (from 40 to 60 years old) and in diabetes history (from pre-diabetes to 20 years of experience) but could be considered from a relatively homogeneous social group – middle class professionals with college to PhD level education. The participants were recruited among research personnel of Siemens Corporate Research, Inc. and from the attendees of the diabetes education center located in Dover, NJ. The interviews were videotaped, transcribed and analyzed using the multiple categorization approach typical for Grounded Theory (Glaser, 1978). However, the scope of the analysis included development of general themes. In the CHAP studies the analysis of the data did not reach the level of theory generation; however, I hoped to achieve more extensive level of theory formation in my subsequent studies.

The interviews allowed me to identify a number of common themes related to diabetes management challenges (Mamykina and Mynatt, 2006). Some of these themes are summarized in Table 1 below.

Observation of Diabetes Support Group

The support group observed during this study was sponsored by the American Diabetes Association certified Diabetes Education Center in Dover, NJ. The center provides a variety of services for individuals with diabetes, including educational courses or consultations with dietitians, in addition to the opportunity to attend meetings of support groups. The number of people in the group varied between 8 and 15, all participants above the age of 40, most above 50, with a relatively even male/female split. The length of participation in the group varied widely, with the most senior tenure of over 8 years, and several newcomers present at every group meeting. Expert dietician affiliated with the center was presented at each group meeting and played the role of group facilitator. The group met every other week during the 6 months of the study. Due to the sensitive nature of the discussions, no video or audio capture was used. Field notes taken to capture observations were annotated and coded.

Cognitive Probe

Earlier in this document I discussed my approach to studies of socio-technical systems through the design and deployment of probes—prototypes of computing applications that engage individuals in the behaviors I wish to study, thus exposing these behaviors to scientific scrutiny. Since my main focus in this first phase of my investigations was on the cognitive aspects of individuals' reflection and their thinking and reasoning, the probe was designed to support these processes; as a consequence it was somewhat different from the probes discussed in HCI literature so far. I use the term *cognitive probes* to refer to these kinds of computing research tools.

Design

CHAP included the following components:

- 1) The GlucoWatch G2 Biographer™ (www.glucowatch.com) – a commercially available glucose monitoring device worn as a wrist-watch that non-invasively samples blood sugar every 10 minutes; the Analyzer software allows viewing the captured records;
- 2) X10 motion detection sensors positioned in places of usual activity, unique for each household (www.smarthome.com);
- 3) A computer-based diary application allowing individuals to report on their activities, composition of meals or medications as well as their emotional state;
- 4) A webcam for free-form comments or notes for the research team. The main purpose of the motion detection sensors was to provide an additional reference for the research team and help assess accuracy of self-reports.

The diary was available from a laptop screen augmented with a touch-sensitive MagicTouch cover to simplify user interaction. Participants could either select from offered lists or enter free-form text. The list of activities was developed with reference to the taxonomy of Activities of Daily Living (Wagner and Groves, 2002), and refined based on the findings of field trials with the Digital Family Portrait. The list of meal types was created based on the food pyramid developed by the Food and Drug Administration (www.fda.org). The participants were encouraged to record activities as they occur, however they could also make entries retrospectively. To allow participants to assess their emotional state, we employed the Self-Assessment Manikin (SAM) (Bradley and

Lang, 1994). SAM allows individuals to report on their emotional state by choosing an emoticon that best represents their emotional state, from sad to happy.



Figure 1: Components of CHAP.

Deployment study

CHAP was deployed in two households for two weeks each. The participants for the study were recruited via recommendations of physicians consulted in the course of the project. The candidate subjects participated in 30 minute interviews to determine their suitability for the study. Subject selection decisions were made in consultation with their primary care physicians. Participants received \$500 reimbursement.

In addition to the monitoring activities described above, the study included daily 30 minute interviews with the participants at their home. The interviews utilized the following structure: the interviewer reviewed the daily records in the diary, asking the participant to elaborate on them or to fill in the gaps. After that, the GlucoWatch was taken off of the participant's arm and the data was uploaded onto the laptop. The participant then was asked to review the readings and comment on them. All the sessions were video and audio taped, transcribed and analyzed.



Figure 2: Participant at home.

Detailed Findings

In this section we discuss detailed findings as discovered by the interviews and observations, and the case-studies of deploying the cognitive probe.

Interviews and Observations

The analysis of qualitative findings was performed in accordance with Grounded Theory (Corbin and Strauss, 1998). All the transcripts were coded by the first author with respect to the patterns emerging from the data, rather than applying a predefined coding scheme. The most prominent themes that emerged from the investigations are presented in Table 2 below.

Diagnosing diabetes

Quotes

Diabetes is often diagnosed late because the symptoms are difficult to observe.

“You are dehydrated, a bit more tired or fatigued, or hungry, but if you work 16-hour days, and it’s summer, that’s how you feel most of the time anyway”.

Often, individuals are diagnosed by accident.

“I had a rash, actually, and I thought it was a poison ivy, because I am very allergic to poison ivy... And I couldn’t stand the itch actually, it wouldn’t stop, and they took a few blood tests and told me – oh by the way, you are diabetic, and my sugar levels were above 400 at the time.”

The first reaction to the diagnosis is usually quite stressful, especially for those with a family history of diabetes.

“When I just got diagnosed, we were all scared [my wife and kids] and we started exercising, we bought bicycles, we went around for a few months, yeah, I think we all joined.” ... “My father-in-law for a long time had a diabetes, and eventually... (shaking his head) ... very horrible end of ... last few years of his life because of diabetes. Yeah. We’ve seen it first hand that it’s not a fun disease when it progresses to the point that you start losing limbs and people lose their eye-sight, so it’s a pretty horrible disease.”

Patients often blame doctors for not stressing the

“I also know now that had I started doing this (controlled diet and exercise) before, I could have

seriousness of the disease early *prevented this. Or at least pushed it off until later on.*
on when they were most *And I wish my doctor told me this, it would give me a*
anxious to address it. *strong motivation for doing this”.*

Monitoring and management

Diabetes challenges *“I mean it’s a big change to your life, it is a food*
individuals’ passive attitude to *change, it’s a way of life change. You have to be more*
health and demands a proactive *active, you HAVE TO be more active. You know,*
management. *sometimes people are just not able to be active. And it*
just makes it difficult, you rather it wasn’t happening to
you than to know...so you deny it...and the more you
deny it... the worse it gets.”

There are significant individual *“... not everybody’s diabetes works the same way, you*
variations in diabetes. *are going to find out as you speak to other people. And*
everybody has their own method, or a plan and you
have to figure it out with your doctor”

Figuring out the optimal *“...it’s definitely tied to your food, you know. Except*
lifestyle is difficult due to high *that it’s not, it does not correlate exactly. So you try all*
complexity of interrelations *sorts of things, you eat later or you have a snack before*
between actions and blood *going to bed. My (blood sugar) was a little high, so I*
sugar values. *would have a snack... and that didn’t work...and then I*
tried eating dinner at a different hour... and that didn’t
work. So you don’t know what works and doesn’t work

sometimes.”

Medication can ease the problem, but is a double-edged sword: it may have long-term consequences, and proactive self-management may seem unnecessary.

“... some of the oral medications make you gain weight too, they make you retain a lot of water, which affects the function of your liver and your kidneys, and everything else, and eventually your heart...” “At the beginning we really paid attention to it...but after a while (after taking medication), I realized that I could have that bowl of pasta at the Italian restaurant and it wasn’t a big deal.”

Identifying the optimal medication regimen is just as difficult, even for clinicians.

“I was on insulin for about 11 years, back and forth, trying different combinations of insulin and oral medication...it wasn’t working...and then I found the right mix of orals that worked without the insulin...There are different strategies we could try, we tried different medications, taking them in a different order, and you always try them for a few months and see how it goes.”

Patients often try to negotiate the compromise between the health and the desired actions.

“Listen, I’ll tell you, when I was young, and I would go on vacation, and if I didn’t have my periods and I was on birth-control pills, I would just manipulate my birth-control pills. And if you have really done that, you know what I am talking about. And I think we all do

that. Well, diabetics that are on insulin they can do that, and if they know that they are going to a wedding where they are going to eat everything they want, they are just going to manipulate their insulin.”

Individuals desire an intensive and frequent engagement of their physician in analysis and reasoning regarding their case.	<i>“In order for me to manage I would have to see him once every week or be able to speak to him once a week and say: these are my numbers right now, what should I do to change the way these numbers look?”</i>
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Motivation and denial

Deprivation of favorite activities may lead to emotional distress	<i>“My doctor tells me: boy, you are a trooper... you need to manage it and you need to not feel deprived. Because once you feel deprived you can sit in the corner and cry. And you can’t allow that, because it is self-defeating.”</i>
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Visual records of monitoring can encourage individuals to at least keep taking the samples	<i>“I think it also helps me to check, because I hate to see a hole in the table, so I force myself to take it so that it’s not discontinued. Because it’s a pain in the neck if I skip a day – I have to make a lot of changes and manually change things, so in the morning I think – yeah, I need to go and poke my finger.”</i>
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Table 2: Emerging themes from diabetes interviews and observations.

One of the strongest themes emerging from the interviews was the need for individuals to engage in the analysis of their disease trying to understand what factors affected their blood sugar and to what degree. Gaining such understanding could allow individuals to make educated choices and maintain that balance between the desired state of health and the desired lifestyle.

Deployment Case Studies

In this section I describe in detail the findings from the deployment of the cognitive probe.

Case study 1

For the purposes of this chapter I will call my first participant Mary. Mary was a native of Georgia in her 80s, who spent most of her life in Atlanta where she worked as a secretary. She had 3 children, a son and a daughter still in Atlanta and a daughter in New York City, where Mary lived in an independent-living retirement community on the Upper East Side. For many years Mary had served as a president of the tenants' social committee: her main responsibilities were in greeting new tenants and helping them to integrate with the community. She no longer served as a president but remained very engaged. Last fall she started taking photography classes.

Mary's diabetes was considered border-line: her blood sugar was generally well-controlled and she took minimum amount of medication. Mary followed a sliding blood sugar measurement schedule (varying the sampling time between different days); however her records were fragmented due to difficulties with the glucometer. Mary had never enrolled in diabetes education classes or consulted a dietitian; her main clinical contact was her primary physician.

Mary had been using a personal computer for several years, mostly to exchange emails with her grandchildren in the South.

Mary's participation in the study was due to her daughter, who convinced Mary to give it a try. Mary, however, adopted a relatively skeptical attitude. She remained very guarded about her life; refused to reveal her exact age, and was careful in sharing any personal details. She also refused to accept the distribution of roles as researchers – study participant. Daily interviews quickly transformed into conversations, covering topics of general interest as much as questions pertaining to the study. In addition, the interviewers needed to be prepared to share just as much personal information as they were inquiring about.

Despite her high sensitivity to privacy, Mary did not have reservations about installing motion detection sensors wherever the research team suggested. The single exception declared off-limits was the bathroom. The final configuration of sensors was as follows: front door; kitchen: counter, by the microwave, by the cat feeder; living room: entertainment unit (by the TV), working table (with all the correspondence), coffee table; bedroom: working table (with a PC) and the night stand. After installation, the sensors integrated in the household without much difficulty. Initial humorous comments regarding the sensors' friendly blinking (the red light goes on when the sensor detects the motion) stopped after the first few days and there was no mention of the sensors after that.

The first few days of the study demonstrated that the research team had grossly underestimated the complexity of the GlucoWatch. Physical assembly of all the device parts necessary to put it on presented a barrier that Mary was only able to overcome

during the last few days of the study. After several unsuccessful attempts, Mary requested that one of the researchers be present during the assembly, and one during the calibration, 2 hours after the assembly. Only in the last 3 days of the study, both the assembly and the calibration were performed independently and successfully.

Case Study 2

The second participant, Paul, was an 80-year old New Yorker, still only semi-retired, as he continued to manage an investment portfolio and real estate leased to various businesses in the greater New York area. He lived with his second wife, Monica, who was retired as well. Paul had two children from his first marriage, a son and a daughter, both living remotely, and five grandchildren.

Paul became an avid computer user about 3 years ago, was managing his investment portfolio online and had an extensive email exchange with like-minded individuals, often regarding prominent political or social issues.

Paul, in his own words, had a very elaborate medical history, including experience with triple bypass and prostate cancer. He followed a rather strict medication routine, using medication dispensers to organize his pills and vitamins on a weekly basis.

Paul's diabetes was discovered by an accident after an adverse reaction to a medication. Physicians involved with diagnosis did not stress the importance of immediate lifestyle adjustment, and Paul continued consuming juices and sweets, which aggravated his state. At the time of the study, however, he was "eating sensibly and carefully" and exercised religiously, either at a gym or at home. He followed a strict daily blood sugar sampling schedule and had several years' worth of written logs. His latest

glucose meter stored the records electronically, thus eliminating the need to maintain logs.

From the first introduction, Paul was enthusiastic about the study and immediately connected with the idea of learning about the consequences of actions with the assistance of computerized tools.

“My feeling is that with a health care provider the vocabulary and the way different people measure pain... so I don’t know sometimes that I am communicating adequately about what’s really happening. And if you have mechanical devices that are absolute in their measurements, the better you can be at solving the problems”

Neither Paul, nor Monica had much reservation in regards to capturing and sharing data collected by the sensors during the pre-study interview. However, during the installation of the probe they requested a detailed description of the sensors’ capturing capabilities, with a particular concern about capture of conversations. Aesthetic considerations led to suggestions that sensors are positioned in discrete places, and not on visible surfaces. A few places declared off-limits included the bathroom and private areas in the bedroom. The final configuration of sensors was as follows: front entrance: by the door, and by the mirror; living room: entertainment unit, exercise bike; kitchen: by the microwave; bedroom: by the bed, by the computer, by the working table.

Even for somebody as intelligent and experienced with computers and technology as Paul, the GlucoWatch presented considerable difficulties. The first demonstration of the device inspired a shower of sarcastic remarks from his wife: “Before you start a patient, do you give them some sort of IQ test? I think this requires a high IQ.” “Yeah,

it's like watching a monkey in a zoo" agreed Paul while going through the steps of the assembly. Several steps demanded a very high level of manual dexterity – pulling out one of the protective layers required a tight grip and could only be accomplished using pliers. However, Paul was eager to solve the puzzle; after carefully reviewing the instructions he was able to assemble and calibrate the device without any assistance on the second day of the study.

Discussion

In the introduction of this chapter, I presented a number of research questions. Below I generalize my findings to address these questions:

Current Management Practices

A more detailed account of themes that emerged from the qualitative study is presented in Table 2. The three recurrent aspects of diabetes management were as follows:

The Need to Become a Detective

The main goal of all diabetes management activities is to keep patients' blood sugar at a consistent level as close to the "normal" as possible. The management techniques usually involve a diet low on carbohydrates and sugars, regular exercise and appropriate medication. While there are general guidelines regarding management strategies, developing a well-suited care plan remains a significant challenge for each newly diagnosed individual.

"I am looking for answers to my questions, and I want them to be definitive, and nobody can give me any."

These words of a frustrated new patient are exemplary of numerous similar comments. Great individual variability of diabetes prevents physicians from devising precise guidelines that are applicable to all patients. Instead, individuals are taught to become increasingly sensitive to their health, recognize symptoms of low or high blood sugar and become more attuned to individual reactions to different types of foods, exercise and medication. “We try to teach them to become detectives” commented a nurse at the education center, and indeed it takes the mental acuteness of a detective to discern the patterns that lead to the successful management. Unfortunately, the current way of tuning management practices comes down to a trial and error process:

“You try something and you keep your fingers crossed, and then you see that it doesn’t work, and you try something else.”

Flexible Negotiation of Actions

One of the recurrent themes in the discussion of the diabetes support group stressed the importance of the balanced lifestyle for individuals with diabetes. Drastic changes, common for the newly diagnosed patients, quickly lead to the feeling of deprivation and often prevent long-term adoption of the necessary restrictions.

To ensure enduring lifestyle change, the facilitators of the group stress the need for intelligent moderation or compensation, rather than full exclusion.

“I try to tell them – if you are going to a party and you know you will want that piece of cake, that’s ok, go ahead and have it. But then have something really light for breakfast. Or dance at the party for a couple of hours.”

Assisting individuals in flexibly negotiating their actions and finding the right balance between pleasurable activities and the desired state of health was seen as one of the main targets of the diabetes education.

Importance of Motivation

Introduction of restrictions in the lifestyle can be a painful process for individuals with diabetes. The need to follow a particular diet makes travel, corporate, or family functions problematic:

“We went to my husband’s family function, and there was nothing there I could eat. She (sister-in-law) didn’t even have a tossed salad. Sitting with an empty plate is embarrassing.”

Moreover, the necessary restrictions need to be persistent throughout the life of the individual. The commitment to the low-risk lifestyle is influenced by a variety of factors that can provide both motivation and discouragement:

“Actually, if I have a string of a few days of low numbers, I feel more encouraged to keep it up. Yeah, but then the numbers would come up and then you feel – ah, well, if its up already ...”

Health Reasoning

Decision Cycle

Individuals’ ability to successfully manage diabetes largely depends on their understanding of the correlations between daily activities and blood sugar levels. I developed the following framework to illustrate the steps necessary to achieve such understanding. While this framework is only a rough approximation of the actual

decision-making process, it highlights the barriers in the current practices and suggests ways to enhance them with computing applications.

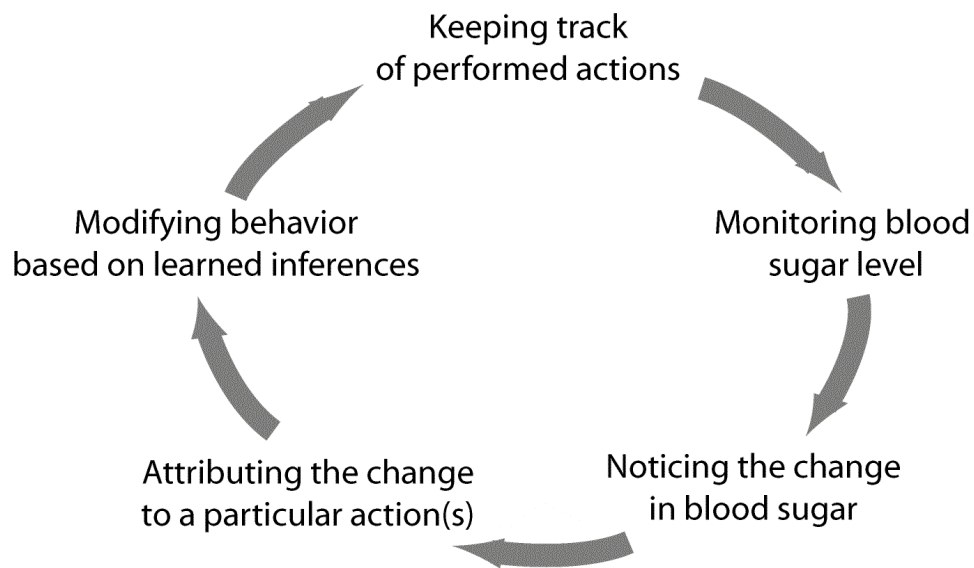


Figure 3: Diabetes decision cycle.

The cycle begins with individuals keeping track of their actions. There are two types of actions: interventions are intended to modify conditions, such as medications or exercise; nominal actions may still lead to a change in conditions, but without such intention. Careful monitoring of the blood sugar level allows individuals to notice changes in blood sugar during the day. Once a particular pattern of change is recognized, it needs to be attributed to a particular action, either nominal or interventional. Establishing such correlations enables individuals to modify behavior based on learned inferences – reinforce actions that lead to positive outcomes, and inhibit actions that lead to negative outcomes.

While successful management requires tight connection between these steps, there are numerous gaps, disconnects and break-downs that force individuals to engage in a lengthy and laborious trial and error process.

Keeping track of one's actions is notoriously difficult. Meal diaries, often suggested in diabetes, are rarely strictly followed and are usually recommended for short periods of time or in special cases. Painful fingerstick blood sugar sampling techniques prohibit probing beyond a few times a day. Such infrequent sampling may highlight longitudinal trends, but does not reveal the daily patterns. Consequently, attributing change in the blood sugar to a particular action is non-trivial. The last step of this cycle, action modification, presents a significant challenge in itself: full understanding of the negative consequences of certain actions may not guarantee the necessary change in the health behavior. In fact, this last step, individuals' ability to modify their behavior given full understanding of consequences, was challenged by the many physicians consulted in the course of the project.

Hypothesis-Based Reasoning

I introduced the cognitive probe to engage the participants in reflective explorations of and reasoning about the possible correlations between their activities and changes in the blood sugar readings. As different as my two participants were, daily interviews pointed to the similarity in their reasoning approaches. In both cases, within the first few days of the study, the participants formed a hypothesis regarding a particular causal relationship. Once the hypothesis was formed, they carefully monitored the data seeking evidence relevant to their hypothesis.

Despite all the difficulties with the technology, the participation in the study heightened Mary's awareness of her daily readings, taken with both the GlucoWatch and the regular glucose meter. During one of the first days of the study days, her attention fell on a somewhat higher reading after eating a breakfast cereal containing raisins.

“You know, I am starting to notice that every time I have this new cereal, my blood sugar goes up; can it be possibly true?”

Any negative consequence of raisins, as a natural product, seemed counterintuitive to Mary; however, this suspicion required further investigation. Each subsequent day’s readings increased Mary’s confidence in her conclusion. By the end of the study she was convinced that raisins led to the rise in the blood sugar. Dieticians consulted during the study confirmed the suspicion – due to their high glycemic index, raisins, as well as grapes, lead to a quick rise in blood sugar value. This discovery changed Mary’s skeptical attitude to health monitoring; by the end of the study she was contemplating extending her participation.

Paul took a structured scientific approach: he spent the first day of the study keeping a close watch of the GlucoWatch readings while experimenting with actions (how quickly would my blood sugar change if I had a glass of orange juice?). He also sampled his blood sugar with a conventional glucose meter 5 times in one day to assess the accuracy of the GlucoWatch readings. The first event that drew his attention was a considerable jump in the values captured within a half an hour period:

“Could there? Does that make sense? Because other than the orange juice as a trial, I didn’t eat anything. But I did have some excitement. I wasn’t too excited, but may be I was because I was raising my voice more or less. Is that emotional involvement, is that possible?”

Thus the first hypothesis was created. When discussing this event during the daily interview, Paul already presented it as his first discovery:

“Ok, so what I did was frustration with staff in setting up appointments for an MRI and consultation with neurosurgery. And that may have been, that may have affected the glucose inside.”

During the subsequent days of the study, Paul paid close attention to his emotional state, going through SAM questionnaires, and even noting all agitated conversations in notes. All the subsequent readings seemed to confirm the suspected relationship between the emotional state and the high readings. Interestingly enough, he formed no new hypotheses, at least in the duration of the study.

These findings demonstrate the success of the cognitive probe: for the first time in their lives, our participants had access to such extensive retrospective records and could engage in reflective analysis. It also showed that access to these detailed records inspired individuals to engage in active experimentation rather than passively contemplate the collected data. At the same time, there were a number of limitations in the participants’ learning experience and, specifically, in their experiments. Below I discuss the main limitations of experimentation and discovery possible with CHAP, namely, the disconnect between reflection and action, lack of tools and mechanisms that could support continuity in thinking, and the need for articulation and social validation of opinions.

Opportunities for Future Research

Authentic Learning Opportunities

One of the main objectives of CHAP as a cognitive probe and its deployment study was to expose individuals’ thinking and reasoning and make them available for analysis. To accomplish this, the study was designed to include daily interviews with the

participants, during which individuals talked aloud as they mulled over the data collected during the day. This approach certainly had its benefits. Most importantly, it made apparent individuals' hypothesis-driven style of data analysis and discovery. At the same time, this approach created an artificial separation between individuals' daily activities and reflection. This view of reflection as separate from action is not uncommon in cognitive science and psychology. However, some researchers argue that separating these activities leads to an incorrect model of reflection as it happens in the real world. In one of the most compelling accounts of reflection, Schon (1983) argues that reflection is an integral part of action and cannot be separated from it. He coined a term reflection-in-action to describe this view of spontaneous and situated reflection.

Consistently with this view, most of the discoveries reported by the participants happened outside of their interviews with the researchers and were triggered by confusing blood sugar records captured with the Glucowatch at different times throughout the day. These confusing, unexplainable readings prompted the participants to pause and examine their possible causes. During the interviews, and while looking at the aggregated records of the day, the participants revisited their findings and conducted further investigations, for example comparing records between different days. However, no original discoveries were made during these scheduled times for reflection.

Importance of Structured Experimentation

The daily interviews revealed that individuals took a hypothesis-driven approach to the data analysis and engaged in active experimentation. These experiments helped the participants explore the consequences of different actions in a relatively controlled manner, thus helping individuals refine their theories. At the same time, CHAP provided

only a limited support for experimentation, which significantly affected individuals' ability to achieve systematic progress in their understanding. For example, since there was no structured support for keeping track of their experiments, there was quite a bit of redundancy and repetition: records of daily interviews show repetitive mentions of the same food types, such as orange juice or morning cereal with raisins without any noticeable change in the parameters of the experiments. As a result, the participants never advanced beyond their initial hypotheses. In addition, without a clear record of what was attempted, they never gained sufficient confidence in their discoveries, thus further reinforcing the need for social validation, which I discuss next.

Articulating and Validating Opinions

Let us examine once again one of the quotes from the previous section:

“Could there? Does that make sense? Because other than the orange juice as a trial, I didn't eat anything. But I did have some excitement. I wasn't too excited, but may be I was because I was raising my voice more or less. Is that emotional involvement, is that possible?”

This quote is very typical of the interaction between the participants and the researchers during the daily 30-minute interviews. Despite their continuous access to the very extensive records captured over the two-week period, most of the individual discoveries were expressed as hypotheses that required social validation or confirmation, rather than conclusions that were supported with evidence.

One explanation for this phenomenon could be the distribution of the perceived authority and expertise between the researchers and the participants. Despite my repeated assurances of my lack of clinical knowledge, I continued to be perceived as an expert in

both the technological and the clinical aspects of the study. So it is possible that these questions by the participants were reinstating and reestablishing the typical researcher-subject roles. At the same time, studies show that the reason for these questions is deeper and related to the nature of everyday learning. According to Festinger's (1954) social comparison theory, individuals possess a need and a basic motivation to evaluate and validate their knowledge through objective means, when they are available. In lieu of such objective means, validation occurs through comparison of one's opinions with those of others, most commonly colleagues and peers. For example, Festinger, Gerard, Hymovitch, Kelley and Raven (1952) showed that participants of their studies were likely to show less confidence in the validity of their opinions when they found that their colleagues disagreed with them. As a result, individuals had a tendency to conform to the opinions of the majority, regardless of their original ideas. According to this line of research, the participants of CHAP deployment study were likely to seek confirmation or validation of their discoveries from others, even if these others did not possess reliable expertise in the subject matter.

At the same time, the mere fact of engaging in a reflective monologue seemed to be of tangible value to the participants. Even though the main discoveries were made outside of the daily interviews with the researchers, both participants indicated that having the opportunity to speak of their observations and ideas out loud was helping them to structure their thoughts, notice inconsistencies in their reasoning and generally crystallize their findings.

Conclusion

I began my exploration of diabetes self-management practices with open-ended qualitative interviews with individuals with diabetes, pursuing the general goal of uncovering tensions and challenges inherent in diabetes management, and identifying opportunities to enhance these practices with computing technologies. My investigations revealed three main challenges, which included: 1) the need for proactive analytical engagement with the disease in order to develop optimal diabetes management practices, 2) individuals' preference for flexible negotiation of boundaries over acceptance of a completely risk-free lifestyle, and 3) the need for sustained motivation. While all of these challenges presented ample opportunities for research, the need for reflective analysis of past actions provided an overarching theme for my dissertation work.

I designed my first computing intervention for facilitating reflection, CHAP, as a distributed application that helped individuals with diabetes automatically record their relevant past experiences and blood sugar values and allowed them to reflect on the captured records. The deployment study of CHAP included daily meetings with the study participants, during which they reflected on the data captured during the day using talk aloud protocol. This arrangement helped to expose individuals' thinking and reasoning processes and make them available for analysis.

As a result, CHAP helped individuals engage with their disease in the way that was not available to them before. For the first time in their lives, they were able to track the impact of their actions on their blood sugar levels in real time. This immediate feedback prompted individuals to engage in active experimentation, trying different activities and observing their consequences. It also created numerous questions, when

individuals were faced with unexplainably high or low blood sugar levels. These moments of puzzlement and wonder caused individuals to pause, reflect on their activities, and examine possible causes, which often led to discoveries.

At the same time, the deployment study showed a number of limitations in my approach, which opened opportunities for further investigations and provided a ground for my subsequent research and design efforts. Most importantly, it showed that authentic reflection happens in the course of individuals' lives when they experience puzzling situations that need explanation, rather than at separate times when they review their records. In addition it showed that while access to activity and blood sugar records in real time supported individuals' experimentation, lack of mechanisms for structuring the experiments and keeping track of what's been tried before, made the experiments and the resulting learning somewhat fragmented and redundant. Finally, one of the most striking findings of the study was the need for social validation or confirmation of individual discoveries and for the social discourse about the captured data.

I want to conclude this chapter with some comments regarding the platform for monitoring of blood sugar values, the GlucoWatch. This innovative technology undoubtedly has a great potential in promoting reflection, experimentation and learning. The density of records collected with the GlucoWatch made the patterns of daily changes in blood sugar apparent to the study participants, reducing the usual opacity of diabetes. It also significantly reduced the cost of experimentation, in regards to both pain and labor and monetary costs involved. Instead of having to prick their fingers (and pay a \$1 for each test) after each activity individuals were interested in, they could simply observe the changes displayed on the watch's monitor.

At the same time, the device presented a number of challenges of such significance, that they led me to abandon it in my future explorations. It became clear that the complex assembly and operation of the currently available models of the GlucoWatch, might render them inaccessible for untrained individuals. In addition, the accuracy of these devices remains of big concern. For example, one of Paul's questions that remained unresolved was in reference to the accuracy of the readings. Checking each GlucoWatch reading with a finger stick sample was impractical, if not impossible. Thus each new unusual or unexpected reading could be an indicator of an important trend, or a sampling error. Other devices that provide similar capabilities, for example Medtronic MiniMed (<http://www.minimed.com/>) can address both of these issues and provide a more viable platform for clinical monitoring necessary to support reflection in diabetes management.

CHAPTER 5

MAHI: REFLECTION IN SOCIAL SETTINGS

Introduction

I began my investigations with a rather broad goal of designing computing technologies that address the many challenges of chronic disease care. My initial introduction to the work practices of home health nurses—arguably the most patient-centric health care professionals—showed that one of the most promising approaches to chronic disease management is to view the affected individuals themselves as the main agents of care and the primary users of health monitoring applications. Consequently, I conducted several exploratory studies to gain a deeper insight into the nature of self-care and disease management practices of individuals with diabetes. These studies, described in greater detail in Chapter 4 revealed three main challenges associated with diabetes management. One of them, the need for individuals to analytically engage with the diseases through *reflective analysis of past experiences* became the driving theme of my dissertation work.

These initial observations led me to design the first application for facilitating reflection in diabetes—CHAP (Continuous Health Awareness Program). CHAP was designed in the general spirit of health monitoring applications; it focused on automating capture of data pertaining to individuals' diabetes, for example their daily activities, as indicated by their movements around the house, captured with motion detection sensors. These readings were supplemented with individuals' blood sugar values, captured with GlucoWatch, a wearable device that non-invasively measured blood sugar every 5 to 10 minutes. The focus of CHAP deployment study was on individuals' approaches to the

analysis of and reasoning about the captured readings. As a consequence, the study was designed to include a dedicated reflection time, usually at the end of the day, during which the participants were asked to review the data collected during the day and verbalize their thinking about the data using *think aloud* protocol. CHAP was deployed with two individuals with diabetes, both in their 80s, both with a substantial experience with the disease (over 10 years). As a result of their engagement with the application, the participants of the study made genuine discoveries and learned about certain patterns of dependencies between their actions and their blood sugar values. However, the study also showed a number of opportunities to enhance the design of the computing intervention. Specifically, it showed that over-reliance on automated capture and separating capture of the health-related data from its analysis can lead to users' disengagement from the process and missed learning opportunities. In addition, it showed the need for mechanisms that support more structured and continuous experimentation and enable social discourse about individuals' diabetes related experiences and the data they capture.

These new discoveries paved the ground for the new application that I introduce in this chapter, MAHI (Mobile Access to Health Information). MAHI extended the paradigm of health monitoring applications to include a number of features that addressed the three emerging properties of applications for reflection: engagement, continuity and articulation. To remove the somewhat artificial separation between data capture and analysis and to capture reflection that happens as part of individuals' activities, MAHI was designed for a mobile platform—a Java-enabled phone that allowed for interaction anywhere and anytime individuals experienced diabetes-related challenges. Individuals used camera and voice notes features of the phone to record their activities and

experiences, as well as questions, concerns, discoveries, or anything else they deemed relevant to diabetes care (see Figures 4 and 5). To further promote engagement with monitoring, MAHI combined recording of blood glucose readings, captured with a conventional blood glucose meter, with experience sampling techniques that prompted individuals to annotate captured readings at the time of capture. A custom-built Bluetooth attachment to a conventional glucose meter allowed MAHI phone to not only query the meter for the most recent readings, but also generate prompts for the users to use camera or voice note features to record annotations.

One of the findings of CHAP studies indicated the need for social discourse about individuals' diabetes experiences and social validation of discoveries. To support such discourse, MAHI was designed to incorporate participation of a diabetes educator and to be deployed as part of individuals' enrollment in diabetes education classes. MAHI users could then share the data they captured with the educator via a website and discuss it in a message board style.

Finally, to support continuity in thinking and experimentation, MAHI maintained a history of data visually coupled with annotations and discussions, thus preserving the entire history of individuals' engagement with the application and made this history persistent on individuals' websites.

While the general usefulness of health monitoring applications is undoubted, many of the evaluation studies carried on so far focused almost exclusively on qualitative assessments and participant self-reports (Consolvo *et al.*, 2004, Mynatt *et al.*, 2001). Consequently, one of the goals of MAHI deployment studies was to introduce more objective measures of MAHI benefits. MAHI was deployed with 25 newly diagnosed

individuals with diabetes (type 1 and type 2) as part of their 4-week diabetes education program. During this challenging time, individuals acquire basic knowledge of diabetes and develop management skills. Most importantly, during this time individuals learn to reflect on their unique individual experiences. I expected MAHI to contribute to individuals' understanding of the disease, their perception of their role in managing it, and their achievement of the actual management goals.

The results of the study demonstrate that MAHI contributed to the changes in participants' attitudes and behaviors achieved as a result of engagement with the diabetes education. Specifically MAHI helped individuals reach their management goals, such as change in diet. More importantly, however, usage of MAHI had a significant impact on individuals' sense of control over their disease and their perceived role in the management. Participants using MAHI were more likely to report internal locus of control (Wallston *et al.*, 1976) than those in the control group. This suggests that individuals with MAHI experience were more likely to continue active engagement in care and sustain the positive changes achieved as a result of the education.

In the rest of this chapter I will further discuss some important transformations in my understanding of the research and design space. I then present MAHI's design, discuss the deployment study and details of the quantitative analysis of the study results. In the next chapter I will more specifically discuss the nature of individuals' engagement with the application as demonstrated by the results of the qualitative analysis of MAHI usage patterns.

Background

The transition between CHAP and MAHI signified not only and not so much a new design iteration as a rather significant shift in my understanding of the research and design space. I approached CHAP design from the general perspectives of decision-making paradigm, with the primary focus on individuals' engagement with the data, their reasoning and data analysis approaches. The results of the CHAP deployment study led me to broaden my view of reflection. The three most significant transformations included adoption of a sensemaking framework in place of decision-making, focus on authentic situated learning, and appreciation of the social nature of learning, which I discuss below.

Adopting a Sensemaking Framework

Much of the work in enabling and supporting health monitoring tends to be informed by research in decision-making (Patel *et al.*, 2002) that has a clearly defined normative character and presupposes an existence of an "optimal" decision in majority of situations. Studies of decision-making approaches tend to focus on deviations from these golden standards.

In my attempts to enhance lay individuals' reflective thinking about their diabetes, I found decision-making framework to be somewhat constraining. Studies of organization behavior suggested an alternative approach favoring *sensemaking* over decision-making. Rather than focusing on deviations from "golden standards" of good decisions, proponents of sensemaking focus on individuals' ability to make sense of challenging real world situations. "Sensemaking is not about truth and getting it right. Instead, it is about continued redrafting of an emerging story so that it becomes more comprehensive, incorporates more of the observed data, and is resilient in the face of criticism." (Weick

and Sutcliffe, 2005). In accordance with sensemaking my goals in designing MAHI were to help individuals make progress in understanding their disease by providing them with enhanced access to relevant records from the past and helping them shape their reflective thinking skills. Furthermore, MAHI deployment studies were designed to avoid comparisons with “optimal” decisions and focusing on the nature of insights that participants gained during the studies.

Focus on Authentic Learning Opportunities

Reliance on sensemaking suggested a particular approach to the design of the capture mechanisms for MAHI. Rather than helping individuals capture pre-defined activities, such as meals, exercise or medication, MAHI utilizes a more flexible design to allow capturing anything that disrupts regular activities and presents a *breakdown* in a routine.

In the language of sensemaking, breakdowns happen when individuals experience “a fleeting sense of meaning of situations” (Weick and Sutcliffe, 2005). When confronted with an unexpected situation, individuals notice its salient properties and articulate them in language. This realization and articulation of breakdowns serves as a trigger for reflection when individuals become open to analytical engagement with the situation. The notion of breakdowns is particularly relevant for individuals with diabetes. In the weeks and months following the diagnosis, individuals are forced to “problematize” many of their established routines, such as shopping and cooking, participating in social events, and attitudes toward stress or exercise. With time, new behaviors become settled as new routines, which no longer cause breakdowns. However, the time of transition

between one set of routines to another presents considerable challenges to the individuals and opportunities for technological support.

For the purposes of my research I define routine breakdowns as moments in individuals' daily lives when their diabetes becomes the center of their conscious thought and attention. Examples of such breakdowns could be situations when individuals need to make dietary choices (buying groceries, or ordering in a restaurant), or wonder about their health indicators (while looking at the recent blood sugar readings). MAHI provides two ways of capturing such moments: through free-form capture of individuals' accounts of their experiences and through capture of their compensation strategies, such as usage of a glucose meter.

Consequently, MAHI can be used in two modes, as a diary and as an experience sampling tool. As a diary, MAHI allows individuals to record voice notes and photographs (using a cell phone camera) through a custom user interface. As an experience sampling tool, MAHI initiates recording sessions when individuals use their blood glucose meter. At that time, MAHI establishes a Bluetooth connection between the meter and the phone, allowing the phone to query the meter for the recently captured readings and initiate an experience sampling session with a short ring. During the session, individuals are asked to record the reasons for using the glucose meter, and the context of usage by capturing voice notes and photographs. The captured records are packaged by MAHI and transferred to a MySQL database hosted on a secure dedicated web-server.

Social Nature of Learning

One of the most important aspects of MAHI design that I believe distinguishes it from many health monitoring applications is its focus on mechanisms for sharing

captured records and engaging in a discussion. At the same time, MAHI is different from the many commercially available health monitoring technologies in that it does not place the clinical professional in charge of generating opinions and choices. Instead, MAHI allocates them an advisory role in facilitating individuals' sensemaking, but not replacing it.

The strong motivation for this position came from my previous work designing and deploying ubiquitous computing applications that facilitate individuals' reflection on their past activities (Mamykina *et al.*, 2006). The deployment study of my previous application, CHAP, was designed to allow the researchers to observe participants engaged in reflection over records collected during the day (activities, blood sugar values captured every 5 minutes). Most of such end-of-day interviews with the participants followed a relatively stable pattern: when presented with the data collected during the day, the individuals engaged in the reflective monologue, which concluded with the inevitable question directed to the present researcher: "Can this be true?" The individual discovery did not seem to produce reliable knowledge for the participants. Instead, it produced hypotheses that required social validation or confirmation. On one hand, this created a rather awkward situation for the researchers who were able to provide neither the relevant personal experience, nor the expert medical opinion. On the other hand, it brought to my attention the need for supporting social structures necessary for individual knowledge formation.

In the current version of MAHI, I focused on supporting communication between individuals with diabetes and their diabetes educators. A web-based application using PHP offers access to dynamic, password-protected websites where individuals and their

educators can review captured records, and engage in a dialog by providing comments, feedback and additional questions in a message board style (Figure 5). The decision to share records automatically rather than by individuals' choice would not be appropriate for peer-level exchange but is justifiable in the context of high trust in patient-educator communication.

Studying Reflection

Controlled laboratory experiments play a dominant role in the decision-making tradition. In contrast, sensemaking studies tend to rely on qualitative techniques inspired by ethnography. In MAHI deployment studies, I adopted an integrated approach that embraced the complexity and unpredictability of real world environments and situations while maintaining a certain level of theory building rigor regarding changes in people's attitude and behavior.

In my previous work I adopted Technology Probes as a model for my explorations. Technology Probes as research methodology serve dual purpose (Fitton *et al.*, 2004, Hutchinson *et al.*, 2005); on one hand they support certain activities and behaviors, on the other hand they become disruptive research tools that allow investigation of these activities. This dual nature resonates with a research methodology popular in the Learning Sciences domain, known as Design-Based Research (DBR) (Barab and Squire, 2002). Proponents of DBR see their goals as both development of new theories of learning and development of practical tools that facilitate learning in very concrete educational settings. To accomplish this, DBR adopted four important research practices:

- Commitment to understanding of education in real world settings

- Flexible approach to study design that allows for alterations to the variables in the course of the study
- Embracing an active role for researchers participating in the educational process
- Favoring a generative approach over disconfirmation of pre-selected hypotheses

In my deployment studies I borrow from both Technology Probes and DBR

approaches in that:

- MAHI serves as both a research tool to investigate individuals' reflective thinking about diabetes, and an intervention that facilitates this reflective thinking
- MAHI deployment studies were conducted in authentic situations with minimal intrusion from the researchers; at the same time, the researchers took on a proactive role in the education process (one of the investigators taught the diabetes education classes observed during the study)
- While I approached my studies with an initial set of hypotheses, I favored generative approach to theory development. Consequently, much of the analysis focused on qualitative aspects of the study, such as content analysis of the nature of conversations captured on the website and qualitative interviews with study participants. In this chapter I specifically focus on the quantitative results of the study; the following chapter examines in more details the nature of users engagement with the application.

MAHI design

MAHI is a distributed mobile application that includes a conventional blood glucose meter, such as LifeScan's OneTouch Ultra (www.lifescan.com), a Java-enabled cell phone, such as Nokia N80 (www.nokia.com) and a Bluetooth adapter, such as a

modified and custom-programmed Brainboxes BL-819 RS232 Bluetooth Converter (www.brainboxes.com) to support communication between the glucose meter and the phone (see Figures 4 and 5) MAHI was designed to function in authentic real world situations. Consequently, my design focus was on mobility, portability, size, robustness and power consumption. Specifically, I selected a Java-enabled mobile phone to ensure easy access throughout the day. In addition, I took special measures to ensure mobility and durability of the Bluetooth connection. I modified and reprogrammed the Bluetooth converter to be powered by lithium batteries, ensuring uninterrupted functioning for one week. To protect the Bluetooth board and ensure its durability during the deployment, I built a custom plastic case for the Bluetooth converter using a 3-D printer.

Below I describe some of MAHI design choices and theoretical rationale behind them.

The main purpose of MAHI's mobile component is to allow individuals to capture and transmit diabetes-related data with the glucose meter, and annotate them using the voice- and image-recording features of the phone. A common example of annotations was reasons for taking BG readings (e.g., a routine test or not feeling well), and their context (e.g., pre-meal or post-meal). In addition, MAHI is designed to function as a diary, allowing individuals to record their experiences through voice notes and by taking photographs. These records are displayed on individuals' password-protected websites where users can discuss them with the educator in a posting-board style. The posting board also serves as an alternative annotation medium for those users who are more comfortable with writing rather than dictating. The discussions are visually mapped to the

records that inspired them. The websites preserve the history of all the records and related discussions.



Figure 4: Mobile components of MAHI.

Record Number	Date and Time of Capture	Blood Glucose Value	Picture(s)	Audio	Participant's Comments	Educator's Comments
24	2007-06-07 07:23:32				Welcome and thank you for your participation. Tricia	
25	2007-06-07 07:33:04	120		audio_13.mp3	V8=14 JD E/C/S croissant=30 Hi Tricia, I am carb counting. Those are the numbers next to the food product. This meal was 44 carbs. 120 is the exception for an AM reading. Can range from 120 to 180. in this case, yes I had, but only because of the new meal plan. I am not sure how to calculate the carb/I ratio?	Are you carb counting? If so what is your carb/I ratio? Is this a normal AM blood sugar? Do you eat a snack at night? I am not sure if the pic is distorted but I think the carb count would be closer to 45 grams. Thank you, Tricia
40	2007-06-07 12:36:27				there was to be a pic of a hot pockets chix tortilla here with an apple side dish. (41 + 19 carbs) oh well! also, BG was 105. Phone rang but apparently did not send. How can we stop the ringing? how about just once? it wakes up the house.....	Sorry for the inconvenience, I believe you spoke with Lena. Thank you for the suggestion. Tricia
46	2007-06-07 19:38:04	140		audio_19.mp3	half of a roasted chicken (no skin, EWWW), stir fried veggies, 1 cup chick rice (0+5+42) dessert jello fruit cup + some almonds (15+6) high BG could be due to PM snack at 6:00. Tricia, I counted the veggies as 5 carbs. To me, high means that I req'd a shot! My BG numbers are always B4 the meal per dx rule. As you see from the time stamp, the BG reading was about 90 minutes after the snack.	Are you counting the veggies? What makes you think this is a high blood sugar? How much after the meal or snack was this number taken? Thank you, Tricia
54	2007-06-08	140		audio_24.mp3	Good day, I did a reading (149) prior to bed last night, but it did not come across. I only had half of the grapefruit. Carbs this AM.	Are you sure you forgot your lantus? That is not a terribly bad blood sugar. Did you have a snack last night? Breakfast I would

Figure 5: MAHI website (screenshot of the actual site usage). The columns include: 1) record number, 2) date and time of capture, 3) blood glucose value, 4) picture(s), 5) audio, 6) participant's comments posted directly to the website, 7) educator's comments posted directly to the website.

MAHI Deployment Study

Procedures

The deployment study was conducted in collaboration with the St. Clare's Hospital Diabetes Education Center in Dover, NJ. The education program includes a number of personalized sessions with certified nurses and certified diabetes educators and registered dietitians to establish personal care goals, and weekly diabetes education classes, in which the students are familiarized with the physiological nature of the disease and different aspects of care. The two recruitment criteria included age (below 65) and experience owning and using a cell phone (over 1 year) to minimize confounds due to cell phone usability.

I recruited 49 individuals from the newly enrolled students of the center as part of their educational program. The study used a between-subjects design. Half of the participants (25) were assigned to the experimental group, provided with mobile phones, glucose meters and Bluetooth adapters and were asked to use MAHI during the four weeks of the program. Another half (24) was assigned to a control group and received all of the benefits of the diabetes education but did not use MAHI.

Prior to their first class, the individuals were invited for a 45 to 60 minute individual interview and reimbursed \$20. During this time, I 1) discussed the study in detail and obtain an informed consent; 2) asked the participants to fill out the necessary questionnaires, discussed below; 3) the individuals in the experimental group received MAHI and the corresponding training.

Once the classes started, the individuals in the experimental group were expected to use MAHI independently, with no additional meetings with me beyond their

attendance of the classes. During the class time, their glucose meters with Bluetooth attachment were collected for battery exchange. At the same time, the individuals were given an opportunity to ask questions, and discuss their experience with the researchers. I attended and audio recorded all the classes that had recruited participants. Once the classes were completed, the individuals were invited for another qualitative interview and reimbursed \$30.

Assessing MAHI Impact

In the spirit of the Design-Based Research, I approached the study with a set of initial hypotheses and measures of MAHI effectiveness in enhancing individuals' diabetes understanding and management. My main hypothesis was that enhanced personal reflection and opportunity for social validation will have a positive impact on the following three aspects:

- *Emotional state:* In particular, I focused on an individual's sense of control over their health and disease as well as overall quality of life. To measure the impact on the emotional state I utilized the standard Health Locus of Control (Wallston *et al.*, 1976) and Diabetes Quality of Life (Burrough, 2004) questionnaires. My expectation was that MAHI will encourage individuals to adopt internal locus of control (viewing self in charge of one's health rather than placing responsibility on powerful others or chance) more than attending diabetes education classes by themselves. In addition, I expected MAHI to improve individuals' perceived quality of life.
- *Analytical state:* In particular, I evaluated the individuals' understanding of diabetes. The measurement tool, diabetes understanding test was designed by the Diabetes Education Center and routinely deployed to assess the quality of the education. I

expected that individuals in the experimental group will demonstrate higher score on the test than those in the control group.

- *Behavior*: In particular, I assessed individuals' achievement of their management goals, such as change in diet and improvements of actual diabetes management practices including number of meals per day, frequency of exercise per week and frequency of blood sugar monitoring per week. All of these indicators are assessed by the personnel of the center prior to students' enrollment in the classes and upon completion of the classes. Again, I expected individuals in the experimental group to demonstrate higher level of reported goal achievement and behavior change than those in the control group.

Study Results

In this section I focus on the results of the four quantitative measurements discussed above.

General Demographics

A series of two-tailed t-tests performed on general demographics did not reveal significant differences between the two study groups in any of the following: age, gender, race, educational level, diabetes type or severity (measured by the results of the standard diabetes test, Hemoglobin A1C). These results indicated the success of the random assignment of participants into the two conditions.

Overall User Feedback

The overall usage rates of the application and the qualitative interviews with study participants indicated that MAHI became an important part of the diabetes learning for

many of them. Close to half of all participants in the experimental group (10 out of 25) demonstrated high levels of engagement with MAHI and reported high levels of satisfaction with it, illustrated in the following message left by one of study participants on the website:

“Thank you for all of your help and advice - having access to you in almost “real-time” has been very helpful to me, and you have answered many of my questions and provided very meaningful assistance. I feel much more comfortable in dealing with the day-to-day issues of my diabetes, knowing what to expect, and most importantly knowing not to obsess over each and every individual bg reading. I hope that at some point every new diabetes patient will have access to this type of service.”

Different participants valued different aspects of the application. For some the continuous link with the educator was of the utmost importance:

“I feel like a fledgling pushed out of the nest now. It was so great to know that someone is watching over me; now I am on my own.”

Others reported benefiting most from having access to the records themselves:

“Somehow every time I looked at the images of my meals I saw something different than what I saw when I was cooking them. I always thought I was making great choices and then I would look at the picture and think – wait a second...”

MAHI General Usage Patterns

With rare exceptions, the participants demonstrated high levels of engagement with MAHI collecting over 1000 records during the 5 months of the study. The total and average numbers of records and their components are presented in Table 3. The drop out

rate was minimal: only one participant did not complete the study due to health complications (surgery); one other participant completed the study but was not available for the exit interview and post-study questionnaires.

	Sum	Average
Samples	1089	43.56
Glucose	564	22.56
Images	308	12.32
Images of glucose meter reading	67	2.68
Audio	540	21.6
Web postings	419	16.76
Provider's postings	644	25.76

Table 3: MAHI usage patterns.

The twenty five individuals enrolled in the experimental condition demonstrated high variability in their usage of MAHI, with the numbers of records collected ranging from 2 to 135 (Figure 6, Table 4).

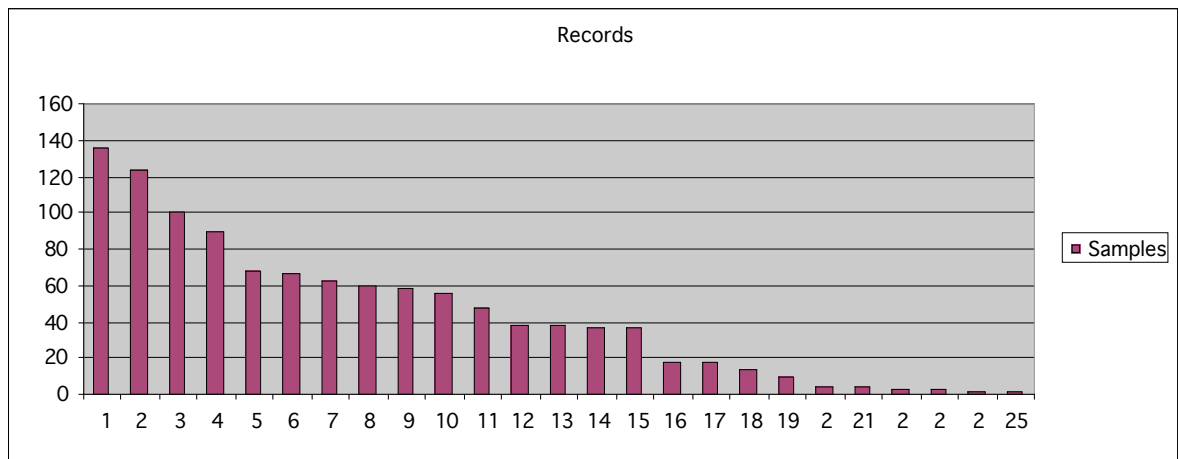


Figure 6: Number of records captured with MAHI.

# of samples	0-20	21-50	51-135
# of participants	9	6	10

Table 4: Participant activity levels.

The initial analysis of participant interviews allowed me to identify a number of reasons for the lack of engagement with MAHI, which included the following:

Technophobia and general technology reservations: many participants in this category experienced difficulties with either using the phone or the website. Some lost access to the Internet during the study and could no longer take advantage of the website (2 participants). Others were generally uncomfortable using phone menus (3). Yet others were intimidated by the expensive-looking phone and were afraid to break it (2).

“I was taught when I was a kid: if it’s not yours, don’t touch it. I am not really good with technology, and I always break things, so I was really afraid I would break something.”

In general, usability issues with Nokia N80 phones were the main source of technical difficulties for the study participants. Most participants actively used phones and their media capture features, however, small size and high sensitivity of buttons made navigation challenging even for younger participants. While I continue to share the enthusiasm for mobile phones as a platform for pervasive health care applications common for the research community, these findings warned me of the possible tension between complex models of phones, such as N80 and users’ desire for the simplicity of interaction.

Lack of time, interruptions: during the exit interviews several participants revealed that they were not able to take advantage of the application as much as they had

hoped due to unexpected interruptions to their participation. These included health complications, family problems, work travel or job transitions (3).

But perhaps the most common reason for low participation was a visibly *low level of personal interest* in the captured records or their analysis (5 participants). Often, these participants dutifully recorded their blood sugar levels, and added comments and explanations. However, they never attempted to engage with the records, either ignoring the website completely, or only visiting it a few times out of curiosity. The post-study interviews revealed an intriguing similarity in these participants' attitudes to health and health care, expressed in the following quote:

“My job is to collect the records for you and for my doctor; it is his job to tell me what these records mean and what I should do about it.”

This observation led me to question the potential correlation between individuals' pre-study locus of control and their level of engagement with MAHI. I report on these findings below. It also further confirmed my expectation that higher level of engagement with the monitoring should enhance learning.

Emotional State

Within this category, I used two standard questionnaires to measure participants Health Locus of Control (HLOC), and their Diabetes Quality of Life (DQL). Both questionnaires are available in Appendices A and B.

The HLOC questionnaire consists of 15 questions that place individuals in one of the three categories: those with internal locus of control (Internal), those with external locus of control who place responsibility on powerful others (External Others) and those with external locus of control who are likely to attribute things to chance (External

Chance). Those with equal scores in multiple categories are placed into the fourth, Neutral group. The main question in my study was whether MAHI could compel individuals to realize and appreciate their own role in diabetes management, and adopt an internal locus of control. Consequently I collapsed across the two external locus categories and looked for the differences between internal and combined external locus of control. The results confirmed my hypothesis: **significantly higher number of individuals switched to the internal locus of control in the experimental group** ($\chi^2=4.17, p<0.05$). In contrast, fewer individuals in the control group reported an internal locus of control at the end of the study; than at the onset; however this difference was not significant. The overall results of the questionnaire are presented in Table 5.

	Control (pre)	Control (post)	MAHI (pre)	MAHI (post)
1	15	13	15	20
2	2	4	4	1
3	5	3	6	4
4	2	1	0	0

Table 5: Health Locus of Control (distribution of participants per loci: 1-Internal, 2-External, Powerful others, 3-External, Chance, 4-Neutral).

An additional question I had in regards to HLOC was whether internal locus of control would lead to higher level of engagement with MAHI for the participants in the experimental group. I found a weak correlation between HLOC and the number of records individuals made using MAHI ($r_{\text{pearson}}=-0.22, p=0.15$, the negative sign is due to the directionality of the HLOC: “1” corresponds to the internal locus) in the anticipated

direction (internal locus of control leads to higher participation), which, however, remained not significant.

The DQL questionnaire consists of 15 questions and returns a numeric value. Analysis of DQL results [by Analysis of Variance (ANOVA)] for both groups pre and post study indicated that there was an overall improvement in quality of life after completing the classes, $F(1,43)=253.25, p<0.0001$). However, there were no significant differences between the groups, $F(1,43)=1.57, n.s.$ The results of the questionnaire are presented in Table 6.

Group	Pre-study	Post-study
Experimental	33.261	29.913
Control	35.5	32.136
Total	34.356	31.000

Table 6: Diabetes Quality of Life (lower score corresponds to higher quality of life).

Analytical State

The Diabetes Understanding Questionnaire was used to assess individuals' understanding of their disease before and after the study. The questionnaire consists of statements about diabetes that needed to be evaluated as true or false. The questions include those referring to physiological aspect of diabetes (e.g., "Insulin is a hormone produced by pancreas, true or false?"), or diabetes management (e.g., "To manage your diabetes you need to exclude all carbohydrates from your diet, true or false?"). Points are taken out from the final score for each incorrect answer. As with the DQL, I found a significant improvement in the participants scores across groups ($F(1,35)=24.98$,

$p < 0.0001$) However, there were no significant differences between the groups ($F < 1$).

The results of the questionnaire are presented in Table 7.

Group	Pre-study	Post-study
Experimental	-2.10	-1.15
Control	-2.24	-1.24
Total	-2.16	-1.19

Table 7: Diabetes Understanding Questionnaire.

Behavior

Finally, in the behavior category I paid particular attention to the achievement of management goals, such as change in diet. In addition I looked separately at three different indicators: 1) individuals' meal patterns (from 1: the least desirable "no stable pattern" to 6: the most desirable "3 meals, 3 snacks") 2) monitoring frequency per week (with more frequent testing deemed more desirable) and 3) exercise frequency per week (with a higher number deemed more desirable). All of these measures were based on participants' self-reports obtained during the pre-study and post-study visits. The results of these assessments are presented in Tables 8 and 9.

The diet goal achievement results confirmed my hypothesis: **individuals in the experimental group reported significantly higher level of diet goal achievement than those in the control group** ($t_{1\text{-tailed}}(45)=3.36, p<0.001$). In all of the remaining behavioral categories, I found a significant improvement for both study groups ($F(1,45)=44.38, p<0.0001$; exercise: $F(1,45)=42.36, p<0.0001$; monitoring: $F(1,45)=88.14, p<0.0001$). However, none of these categories returned significant differences between the experimental and control groups.

Group	MAHI	Control
Diet goals	1.16	1.59

Table 8: Diet goals achievement results (1- achieved, 2 – did not achieved).

	Group	Pre-study	Post-study
Meals	Experimental	2.08	3.56
	Control	1.55	4.00
	Total	1.83	3.77
Exercise	Experimental	1	3.08
	Control	1.14	2.86
	Total	1.06	2.98
Monitoring	Experimental	6.28	15.84
	Control	5.68	15.41
	Total	6.00	15.64

Table 9: Reported behavior changes.

Discussion

One of the goals of MAHI deployment studies was to find objective measures for assessing the benefits of the application. I anticipated use of MAHI to lead to more significant changes along 3 different dimensions: emotional state, analytical state and actual behavior than participation in diabetes education alone.

The findings indicated that both groups achieved significant improvements along all three anticipated dimensions. Especially drastic were the changes in the reported diabetes management with many individuals adopting healthier diets (switching from “no

pattern” to more desirable categories), increasing exercise frequency (often from none to several times per week) and monitoring frequency (often from none to over 14 times per week). These results once again confirm the general benefit of diabetes education as a powerful intervention for individuals with diabetes.

In addition I found that usage of MAHI significantly contributed to individuals’ improvement along these dimensions, specifically in those categories concerned with personal goals. For example, MAHI users were able to achieve their diet goals more so than individuals in the control group.

However, and more importantly, usage of MAHI led to significant changes in individuals’ perception of their role in diabetes management. As I expected, the ability to monitor one’s experiences, formulate and review questions and discuss the records and questions with the diabetes educator resulted in more individuals adopting internal locus of control. Historically, patients have been more than willing to give up any and all responsibility for their treatment to what Wallston and Wallston identified as the “external locus of control: powerful others” in their pioneering applications of the Health Locus of Control. Later studies in diabetes have shown that understanding the patient’s Health Locus of Control can be a key component to improving the patient’s self-management skills in diabetes. Ultimately, the patient’s health belief structure can influence adherence to self-care instructions and metabolic control of diabetes (Wooldridge, 1992). The shift towards internal locus of control indicates that those participants who used MAHI while attending the diabetes classes are more likely to continue active engagement in diabetes care compared to those who were not exposed to the application.

However, I also found that the effect of MAHI was not as strong as I expected, particularly in such categories as diabetes quality of life, diabetes understanding, and in the actual reported behaviors. While most of these categories displayed trends in the anticipated direction, these trends were not significant. There are several possible reasons for this lack of statistical significance in some of the result categories. For example, the diabetes understanding standard assessment tool evaluates a person's generic understanding of diabetes (i.e. book knowledge). This assessment tool is not sensitive to the kinds of increased personal understanding that is more typical of the insights people gained using MAHI. In addition, in such categories as actual reported diet, exercise frequency, and monitoring frequency, the magnitude of change achieved by all the participants irrespective of their engagement with MAHI may have prevented me from seeing the influence of MAHI itself. As mentioned earlier, many of the participants shifted from no management (no meal pattern, no exercise and no monitoring) to adopting stable diets and regular exercise and testing blood sugar at least twice a day. Perhaps the effect of MAHI could have been more apparent if it was deployed after the individuals completed their education. However, qualitative interviews with study participants and educators indicated that for many individuals enrollment in classes leads to the sudden explosion of questions and concerns regarding diabetes; providing the tools that support individual reflection and discovery during that time might have unique benefits and help individuals cope with the new burden of the disease.

General Discussion

The prototype I discussed in this chapter—MAHI—helped individuals capture blood sugar levels and rich media records indicating past actions and discuss these

records with their diabetes educators. The deployment study of MAHI resulted in a relatively high acceptance rate; almost half of all the recruited participants actively engaged with the application and reported high satisfaction rates. More objectively, MAHI significantly contributed to individuals' achievement of their management goals (diet). Even more importantly, it helped its users realize their role in diabetes management and adopt an internal locus of control. Research shows that internal locus of control is more likely to result in continuous engagement in self-care and lead to more sustained behavior changes (Wooldridge, 1992).

Encouraged by such positive findings, my next aim was to explicate particular MAHI features that contributed to these results and examine whether MAHI's focus on engagement with the monitoring, continuity in thinking and experimentation and articulation of understanding played an important role in individuals' learning process. I present a more thorough analysis of individuals' engagement with MAHI features in the next chapter. Below, I discuss one of the more salient distinctions between CHAP and MAHI, introduction of social context for learning through the ability to share and discuss captured data. This ability, which was viewed by the study participants as one of the main advantages of the application raised a question of importance for my general argument in this document. If automating data capture leads to users' disengagement from the monitoring process and impedes learning, is there any value in automating such capture?

Sharing Data

For many participants, engaging with MAHI presented a certain challenge: they were not sure what to capture, how often and what questions to ask. However, in many such cases, after a short period of time, there emerged a particular pattern: either the

individuals or the educator would identify a problem based on the captured records (for example, unusually high fasting morning blood glucose reading). The educator would often continue the exchange by asking probing questions about possible reasons for the problem or advancing plausible explanations, framed as hypotheses, inviting the participant to join in the analysis. In this way the educator was able to coach the participants through reflective analysis, demonstrating it by example and providing guidance on the way. For many participants these coaching sessions became the most valuable experiences of the study:

“Half the time I didn’t even answer her questions. But I knew that those were questions for me; this is how I should be thinking. Now I can look at these records and I know what to look for and how to look for it.”

Access to Data

The observations above lead to a question of whether MAHI could have had the same effect without the complexity of custom hardware and mobile application for automated data capture. Could a simpler message board allow for the same exchange and experience? Interviews with study participants indicated that sharing access to data was essential for both the educator and the participants. For example, it presented visible triggers (problems in the records) for initiating conversations. While all individuals enrolled in the classes are continuously encouraged to contact the educators, those contacts are rare in either direction. At the same time, the data allowed the educator to shape the questions and the coaching in way meaningful to the participant:

“Otherwise, I would just have to ask the same questions of everybody and it is very hard to engage people with generics.” (Educator)

As a consequence, I argue that sophisticated sensing techniques that target different indicators or health and various activities can be of great importance. However, these techniques need to be combined with mechanisms that engage individuals in the monitoring in addition to automating it.

Designing for Long-Term Adoption

Many of my participants mentioned that such intensive and focused exchange with the educator is most beneficial at the beginning of their engagement with diabetes management. At that time one's management skills and reflective thinking are beginning to take shape and can benefit from feedback and guidance. However, the same intensity can hardly be sustained beyond the initial weeks. After this time, individuals often continue refining their skills by engaging not only with the educator, but also with a community of peers through face-to-face or online support groups.

My next application, Di-Tag was inspired by the idea of learning through participation in a community of practice. It used capture techniques similar to the ones employed by MAHI, but augmented the educator-participant dialogs with an ability to share experiences with a community of peers. However, sharing the data with non-experts called for additional rigor in articulating findings and discoveries. Consequently, Di-Tag employed a number of new features to support structured articulation.

CHAPTER 6

ANALYSIS OF REFLECTION WITH MAHI: EXPLAINING THE IMPACT

Introduction

In this document I describe my investigations of the role of computing technologies in facilitating reflective analysis of past activities. The importance of such analysis is hard to overestimate, especially in regards to the management of chronic diseases, such as diabetes. Due to the high individual variability of cases, each person with diabetes must repeatedly revise and refine their approaches to diabetes management based on their own history and experiences. Consequently, individuals need to adopt a highly inquisitive and *reflective* mindset, paying close attention to patterns of change in their blood sugar values and investigating the causes of these changes (Bodenheimer, 2002).

In the previous chapters I discussed a trajectory of applications I designed to help individuals engage in reflective analysis of their past experiences. These applications also served as research tools that allowed me to study individuals' approaches to reflection, revealed individuals' learning styles and suggested new ways to enhance learning with computing technologies. The first application I introduced, CHAP led me to hypothesize that introducing higher levels of automation of data capture and separating data capture from its analysis may lead to individuals' disengagement from the monitoring, thus impeding their learning. Instead, I focused on investigating techniques that promote active attitude towards health monitoring, and reduce the separation between capture of health data and its analysis.

To address these new opportunities, I have designed my next application, MAHI (Mobile Access to Health Information) to integrate mobile and ubiquitous capture components with a number of features for engaging individuals with the monitoring. Specifically, MAHI encouraged individuals to annotate the captured data, such as blood glucose readings, at the time of capture and discuss this data with a diabetes educator. In addition, MAHI preserved a history of the captured data, visually coupled with annotations and discussions.

In the previous chapter I discussed the quantitative results of the deployment study that specifically focused on MAHI's impact of various aspects of individuals diabetes care, including their understanding of the disease, their attitude towards self-care and their actual behavior. The study demonstrated that MAHI helped individuals achieve their personal diabetes management goals, specifically diet goals. More importantly, it showed that several weeks of engagement in reflective analysis of past diabetes experiences with MAHI led individuals to embrace a more proactive attitude towards their health, indicated by their adoption of the Internal Locus of Control (Wallston *et al.*, 1976). These two findings together indicate that study participants not only were able to improve their approaches to management during the study, but also were likely to sustain the positive change even after the study ended.

These positive findings showed that computing applications can have real benefits for individuals with diabetes. The question remained, however, as to what MAHI features contributed to these improvements, what learning style MAHI users embraced, and how specifically they engaged with the application. To answer these questions, I conducted an in-depth analysis of MAHI usage records collected during the study.

Qualitative analysis of these records using techniques common for the Grounded Theory approach (Corbin and Strauss, 2004) revealed a similarity between participants' learning process and a style of learning known as "cognitive apprenticeship" (Collins *et al.*, 1989). In this chapter, I argue that MAHI allowed educators to expose students to the expert model of diabetes, demonstrate expert approaches to solving diabetes-related problems, and help students integrate these approaches into their own practices. In particular, I argue that MAHI provided critical learning support by combining the more traditional tools for automated capture of health and activity data with features that 1) help individuals articulate opinions through annotations recorded at the time of capture, 2) promote coherence in learning by enabling contextualized discussion threads and 3) encourage metacognition by retaining persistent history of data, annotations and discussions.

In the rest of this chapter, I present some additional background review not included in the previous chapters and further discuss the concept of cognitive apprenticeship. I then discuss the details of the learning process as it unfolded during the deployment study, and the role of MAHI in this process. I contrast learning with MAHI with learning that was observed in the control group; this group included individuals who took the same classes but did not use MAHI. I conclude with general thoughts on incorporating social-scaffolding mechanisms into the design of ubiquitous-computing applications.

Background

Adopting Apprenticeship as an Instructional Model

In the previous chapters, I discussed the tension in the field of learning sciences between socio-cultural theory of learning, which views knowledge as deeply embedded in social and cultural context, and the more traditional view of knowledge as abstract and de-contextualized, and learning as belonging in classrooms. The earlier views can be traced to the writings of Russian psychologist Lev Vygotsky and his notion of Zones of Proximal Development (ZPD). Vygotsky defined ZPD in the following way:

“the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers.”

(Vygotsky, 1978)

More recently, Albert Bandura further developed the concept of learning in social settings and with the assistance of others in his Social Learning Theory (Bandura, 1977). Consistently with Vygotski, Bandura argues that people learn by observing others' behavior, attitudes, and outcomes of those behaviors:

“Most human behavior is learned observationally through modeling: from observing others, one forms an idea of how new behaviors are performed, and on later occasions this coded information serves as a guide for action.” (Bandura, 1977).

Social learning theory explains human behavior in terms of continuous reciprocal interaction between cognitive, behavioral, and environmental influences. Bandura also further developed the notion of scaffolding, which refers to techniques and approaches that educators can use to help students acquire new skills and knowledge.

One of the better-known examples of contextualized situated learning is apprenticeship; an insightful account of professional and non-professional apprenticeships was presented by Lave and Wenger in their analysis of *Communities of Practice and Legitimate Peripheral Participation* (LPP, Lave and Wenger, 1991).

The view of learning through apprenticeship inspired a number of new approaches to more formal education. One such model, cognitive apprenticeship (CA), described by Collins, Brown, and Newman (Collins, Brown and Newman, 1989), brings some aspects of apprenticeship into the traditional classroom. Just as in apprenticeship, educators enact skills to be learned rather than explain them through formal rules, and students learn by observing and imitating. However, there are several distinctions between CA and more traditional types of apprenticeships. Most notably, in CA, the notion of community of practice is replaced by the notion of an educational community; the masters, or in this case teachers, are, in a way, outsiders to the community of learners. In addition, most traditional apprenticeships focus on creating certain artifacts (intellectual or physical). In contrast, in CA the final product of the community is learning itself. Finally, CA places greater significance on the transfer of skills between domains, which is largely unnecessary in traditional apprenticeships.

Collins, Brown, and Newman describe learning with CA as a three-step process: (1) Masters or teachers demonstrate their skills to the students; (2) masters provide coaching and scaffolding for students as they imitate masters' approaches until becoming proficient with the new skills; and (3) teachers remove scaffolding once they have evidence of students' mastery. One of the main challenges of CA lies in making the

cognitive processes of teachers and students mutually visible, to enable both demonstration and coaching.

Cognitive Apprenticeship builds upon both ZPD and Social Learning Theory; its main contribution is the focus on the actual learning process and on scaffolding mechanisms educators can use to promote learning.

The learning processes I observed with MAHI exhibited much similarity with the learning envisioned in the CA model, although they unfolded in the context of adult education rather than a traditional school environment. While I did not specifically target CA as a model of learning — MAHI was not designed to support CA, and the diabetes educators were not familiar with this approach to teaching — it unfolded naturally as educators and students engaged with the application. This leads me to believe that CA is a viable model for the learning of complex cognitive skills in the context of ubicomp applications that strive to facilitate reflection and learning from past experiences.

Qualitative Analysis

The deployment study was conducted in collaboration with the St. Clare's Hospital Diabetes Education Center in Dover, NJ. The research team recruited 49 newly enrolled students in the center's educational program. The study used a between-subjects design. Approximately half of the participants (25) were randomly assigned to the experimental group and were provided with mobile phones, glucose meters, and Bluetooth adapters. After a short training session with one of the researchers, these participants were asked to use MAHI for their four weeks in the program. The other 24 participants were assigned to the control group and received all of the benefits of the

diabetes education, but did not use MAHI. Further details of the study design are described in the previous chapter (Chapter 5).

The deployment study resulted in a substantial volume of data, which included the following:

- Students' records made using mobile components of MAHI (1089 samples, each of which included some combination of BG reading, voice note, image, and annotations made through the website)
- Online written discussions between students and educators (419 discussions, many including multiple turns)
- Transcripts of video records of interviews with students and the educator (26 interviews, 45 to 60 minutes each)
- Transcripts of audio records of class discussions for all classes that included study participants (80 classes, 2 hours each)

I took the Grounded Theory (Corbin and Strauss, 1998) approach to the analysis of the captured data. The records made by one of the students from the experimental group, who was chosen at random, were open-coded by two independent coders (myself and a fellow student in the Everyday Computing Lab), with a correspondence rate of close to 75 percent. The two coding schemes were then synchronized, and the final coding scheme was used for the rest of the records. This micro-analysis produced 23 categories of conversational components (phrase-level coding); for example, students' contributions produced such categories as "stating current understanding" and "annotating automatically captured BG", and educator's contributions led to such categories as "indicating trends" and "providing feedback". The complete list of these categories is

presented in Appendix C. Below is an excerpt of the data with the coding categories applied:

Student: I had dinner about 6:00 p.m., and no snack before bed (we went out for dinner, and I wasn't hungry afterwards).**[providing info: solicited, neutral, rich, experience, external, specific]** When should I have a snack - several hours after dinner? Right before bed? Is something like a granola bar a good snack? **[asking questions: actions, new, specific]** Thanks for your help **[token: polite ending]**. Peter///
OK, I'll give it a try and we'll see what happens. **[Answer: experimentation/planning]**

These phrase-level categories were then combined to produce higher-level conversational patterns (conversation-level coding). Examples of these higher-level categories include “Problem Solving” and “Behavior modification.” Below is a list of the higher-level categories (E refers to the Educator, S refers to Student):

Hook

Driven by	Educator
Trigger	Any new record in the table (or sometimes lack of new records)
Common Pattern	E (asking for clarification or stand-alone questions) → E (Shaping Understanding: Diabetes Teaching)
Resolution	Hooks may have no resolution at all, or may just end with opportunistic teaching by E

Problem solving

(breakdowns)

Driven by	Student
Trigger	A breakdown reported by the student (most commonly a BG value)
Pattern	S (Annotating BG, Voicing ad Problem) → E (Asking for clarification/Diabetes Teaching) → S (Answering Questions/Providing Information) → E (Providing Recommendation)
Resolution	Either a recommendation or explanation from E (and possible commitment from P)

Behavior modification

Driven by	Educator
Trigger	A problem identified by the educator but unnoticed by the student
Pattern	S (Annotating BG) → E (Indicating Trends/Providing Feedback/Diabetes Teaching)
Resolution	Either a recommendation or explanation from E (and possible commitment from P)

Experimentation

Driven by	Student
Trigger	External
Pattern	S (Annotating BG/Awaiting results of action/setting up next

	conversations) → E (providing feedback/making a recommendation/diabetes teaching)
Resolution	A conclusion from a student, with a possible feedback from the educator

Reflecting on patterns (or previous thinking)

Driven by	Either
Trigger	Unusual (problem or improvement) BG value
Pattern	E (indicating a trend) or S (Voicing a problem) → S (Stating current understanding) → E (Providing feedback/acknowledging student's self-efficacy)
Resolution	Feedback and encouragement from E

Testing Theory (either)

Driven by	Either
Trigger	Unusual (problem or improvement) BG value
Pattern	S (Sharing Experience/Stating Understanding/Asking questions/Soliciting advice) → E (Asking for clarification/Asking questions) → S (Providing information/Answering questions) → E (providing feedback/making recommendations/acknowledging students' self-efficacy)
Resolution	E either confirms or corrects P's theory

Extending knowledge

Driven by	Either
Trigger	External (not something captured with MAHI)
Pattern	P (asking a question) → E (asking for clarification) → S (providing information) → E (diabetes teaching/recommendations)
Resolution	Feedback/teaching/recommendation from E

Basic feedback loop

Driven by	Either
Trigger	New record
Pattern	S (Sharing experience/Annotating BG) – E (Acknowledging student self-efficacy)
Resolution	Acknowledgement from E

Table 10: Categories of coding.

Learning with MAHI

A significant part of all the conversations captured with MAHI (more than 50 percent) and much of the learning evident in MAHI revolved around solving specific diabetes-related problems. These included troublesome BG values, weight gain, or puzzling food labels, among others. These problem-solving conversations followed a relatively consistent pattern, which included three stages. These stages can be viewed from two human perspectives, that of the educator and that of the student. In the initial stage, *Demonstration/Observation*, the students and the educator identified, discussed, and articulated problems. After that, the educator demonstrated her problem-solving approach to the students, exposing them to her own model of diabetes. During the second

stage, *Coaching/Internalization*, students internalized new knowledge or skills, for example by experimenting with new diabetes management practices, while the educator observed students' experiments and provided coaching. Finally, students demonstrated their mastery of the new knowledge or skills, thus signifying the *Withdrawal/Mastery* stage and the cue to withdraw the scaffolding.

While these three phases were not always neatly distinguished and didn't always present in a clean sequence, they were generally present in one form or another in the majority of all the online conversations. I believe that following these steps allowed the students to create and continuously refine an operational model of diabetes, which they could use as a basis for future problem-solving activities. In Table 11 below, I summarize these perspectives together with the design features included in MAHI to support them and the impact that these features had on the learning process.

<i>Educator</i>	<i>Student</i>	<i>Design Feature</i>	<i>Impact</i>
Demonstration	Observation	Annotations	Articulation
Coaching	Internalization	Contextualized Discussion Threads	Coherence
Withdrawal	Mastery	Persistent History	Metacognition

Table 11: Stages of the learning process from the perspective of an educator and a student, and design goals for computing systems supporting learning.

In the subsequent sections I describe the details of the three phases of the learning process and specifically focus on the three design components of MAHI that supported the learning.

Demonstration and Observation

During the initial stage of the problem-driven learning process, the educator and the students were united by the common goal of addressing specific problems that the students encountered in their daily life. The main activities during this phase included *identifying problems, formulating problems, and investigating problems*.

Identifying Problems

As I mentioned earlier, many conversations captured with MAHI (more than 50 percent) began with a statement of a problem. Some of these problems, most commonly high BG values, were noticed by students and constituted *breakdowns* or disruptions of their daily lives, which was evident from their annotations:

Blood glucose value: 165

S3 (audio record following BG reading): This is my early morning fasting reading and I don't understand why I can't seem to get this number down. My numbers during the day are between 115 and 200, but my morning ones are always high.

Other situations, while considered problems by educators, were not viewed as such by students because they did not cause a breakdown. Common examples include sub-optimal dietary choices that did not immediately lead to increases in blood sugar. In these cases, the educator knew that the cumulative effect of such choices would eventually lead to problems, but the students could not see the potential effect. Not surprisingly, the evidence of learning in the data was more pronounced in those conversations that were initiated by actual breakdowns. This finding is consistent with the view of learning as driven by problems or breakdowns (Weick and Sutcliffe, 2005)

and my own expectation that reflection is triggered by breakdowns in routine activities.

Sometimes it took a relatively big problem to inspire participants to engage with MAHI:

BG: 315

P36 (audio record following BG reading): My reading was 315. I don't know if that was fruit. I feel strange; I have not had a high reading like that in a long time. Ok I am going to have to start to write down what I was eating.

Formulating Problems

Even in cases when students recognized a problem, some additional discussion was often necessary to reach an agreement regarding the nature of the problem.

Oftentimes this discussion started with students' own sentiments regarding the readings they captured. At other times, it involved clarifying questions from the educator that prompted the student to further elaborate on and formulate the problem:

Audio 153: These last two days things have not been really great; I've just been coasting along...

E: what do you mean just coasting along? Is something bothering you regarding your blood sugar levels?

Investigating Problems

Finally, once the student and the educator reached an agreement regarding the nature of the problem, the educator applied her own knowledge of diabetes to investigating the cause of the problem. Most commonly, this phase included a series of questions from the educator that would tackle plausible explanations. For example, the

student's comment in the first excerpt in this section led to the following response from the educator:

E: That is a very common question and also frustrating. What time was dinner? Did you have a chance to consume a snack? The long time span between dinner and AM often causes the increased number. Remember that after about 4 hours the liver needs fuel. A snack of 1 cup of milk or 1/2c fiber cereal + 1/2 c lowfat milk will help bring this number down. It will delay sugar production.

This last phase, the investigations of the problem by the educator, served a dual purpose. On one hand, it allowed the educator to enrich her own understanding of the student's condition and collect information necessary to suggest a solution. On the other hand, and most importantly, it allowed the educator to expose the student to the educator's model of diabetes and her approach to solving problems. During these question-answer sessions, the educator demonstrated to the students salient properties of actions — such as the timing of snacks or the texture of carbohydrates in the meals — how to form hypotheses, and how to use data to test the hypotheses. For example, in the excerpt above, the educator formed a hypothesis regarding the cause of the problem (long stretch of time between meals) and asked questions to test the hypothesis (the timing of evening snacks), at the same time explaining her thinking to the student.

During these question-answer exchanges, students were actively engaged in observing the educator, paying close attention to her questions. Many participants viewed these “back and forth” troubleshooting sessions as the most valuable aspect of the study and their participation:

“Well, when I would get up in the morning and I had taken my blood sugar, and

then you know, she'd say "what have you eaten previously?" and it would get me started... and I wouldn't necessarily answer her questions, but it would prompt me to think about what she's asking me and think about what I had done and why blood sugar was up or down..."

Articulation with MAHI

The main task of the computing system during the early stages of learning was to assist the educator and the students in *articulating* the problem and its causes. The term "articulation work" has gained a somewhat extended meaning within the CSCW community, referring to any activity necessary to support collaboration, including scheduling and coordination (Crabtree *et al.*, 2006). Here I use it in its more traditional narrow sense, as referring to activities concerned with enunciation of meaning rather than coordination of actions. During the first phase of learning, MAHI provided articulation support on three different levels: (1) allowing students to *capture* the actual breakdowns and data that could help the educator notice problems that did not cause a breakdown; (2) allowing students to formulate and articulate problems often through *voice notes*; and (3) allowing educators to investigate problems through *contextualized discussion*.

Capture

Not surprisingly, one of the main indicators of problems for the students were abnormally and undesirably high or low blood glucose levels captured with the glucose meter, transmitted by the phone, and displayed on MAHI website. Frequently these captured readings led to a quick implicit agreement between the educator and the student regarding the nature of the problem:

Captured blood glucose: 161

Educator: Have you changed your snack?

P1: I had dinner about 5:30, but then I had 1/2 a chocolate bar around 10:00. Obviously not a good idea.

In this example, neither the educator nor the student explicitly acknowledges the problem (high blood-sugar value). Instead, they do so implicitly: the educator by asking a question, thus implying that the value needs an explanation, and the student by negatively assessing the snack choice.

In addition to BG records, rich media records collected by the students often gave the educator sufficient insight to the problem's nature for the formulation of appropriate follow-up questions. The excerpt below shows an example of a problem (high proportion of carbohydrates in the meal) that did not cause a breakdown for the student but was noticed by the educator.

P5:



E: Did you finish this? How many carb servings do you think you had?

Voice Notes

MAHI was designed to function as both a diary and an experience-sampling tool, prompting the participants to make a recording (voice and/or picture) to explain the nature of each glucose reading. While this feature was included mainly for the benefit of the educator and the researchers, to provide context for BG readings, it produced valuable benefits for the participants as well. Having the opportunity and the encouragement to make a record while viewing freshly captured blood-sugar readings made many

participants pause and think about their numbers, form an initial impression, and at times contemplate potential reasons for certain values:

Captured BG: 177

S24: (audio record following BG reading) Hi, this is Julie. I just took my blood sugar reading, 2 hours following breakfast. I am shocked; my reading was 177. That was after I ate Kashi Strawberry Fields, but I also took my insulin 15 minutes ago, I didn't get it in before my meal. So... may be that's what happened. I am in shock.

During the interviews, the participants confirmed that first moments after viewing newly captured blood glucose readings were usually moments of reflection for them:

“Like I said, you know, with us I think, you know, you see a high number and the first thing that goes through your mind is “dude what did I eat that was wrong?” You know? Or “how much did I eat that was wrong?” (S4)

And for many of them, having the opportunity to capture thoughts and questions then and there was important because:

“nine times out of ten, by the time you go home, you forget what it is that you [thought or] wanted to ask.” (S9)

Contextualized Discussion:

As I discussed above, captured records of students' activities provided the educator with rich context for students' glucose readings. Often it was enough for the educator to identify the cause of a problem.

In other cases, or for those participants who only made sparse or text-only records of activities, the educator could use the discussion feature to fill the gaps in the records

through questions. And even incomplete and sparse records helped the educator to tailor questions in a way personally meaningful to each student:

“Otherwise, I would just have to ask the same questions of everybody and it is very hard to engage people with generics.” (Educator)

In addition to helping the educator, these questions turned out to be of great value to students, and having a permanent record of the questions next to the activities or glucose readings was a great asset that students referred to throughout the study, which many of them mentioned in their interviews:

“You know, and also I like to go back and check those numbers on the computer. I can go back to that reading and go see what her question was...” (S3)

Coaching and Internalization

During the early stage of learning it was common for the educator to play a proactive role, helping students to identify, articulate and investigate problems. During that time the students played a more passive role of observers and recipients of information. This allocation of roles changed during the second stage when students actively engaged with the new knowledge and the educators moved to the sidelines to observe and provide guidance as needed. The main activities during this phase included: *experimentation, coaching and validation.*

Experimentation

The extensive question and answer exchanges with the educator typical for the first stage of the learning process provided the students with insights into properties of actions that could be manipulated to achieve desired results. During the second stage, the students often engaged in active experimentation with these properties to find a variation

that produced the most desired outcome. Such experimentation was especially common for activities that the students were particularly attached to:

“You know, I was trying to stick with the orange juice in different variation. You know, trying like a low sugared orange juice or less orange juice... because I didn’t want to give it up. You know, I’m stubborn. I didn’t want to give it up. And I ultimately did, but yeah, I wouldn’t do it without a fight, you know” (S8)

Coaching

At the same time as students took more proactive roles, the educator often reduced her engagement to observing students’ actions and providing the necessary feedback and comments. This ability to have an expert “watch over” their actions was most appreciated by the students:

“I think you need somebody to oversee it and say “well, you know, that’s a good idea, but I would do things a little bit differently. I would do this.” You know, not like a school teacher saying, “well, you’re wrong!” kind of thing, but to sort of steer people in the right direction.” (S7)

This coaching was especially important when changes in students’ behavior produced little or no immediate results. In such cases it was important to remind the students to be patient and persist with the changes:

S3, captured blood glucose: 144 (no improvement after incorporating bedtime snack)

E: Give the snack some time...

Validation

Throughout this process, and with the help of the educator, students' confidence in their knowledge increased and they gradually reduced their need for and reliance on the educator's validation. At the beginning of the study, the nascent fruits of students' learning were often expressed as plausible hypotheses, or even as guesses and required extensive educators' feedback:

S3: My morning BG levels often seem higher on the weekends. I usually sleep a little longer on Sat. & Sun. (~ 8 1/2 or 9 hours instead of the usual 8), and I was wondering if this could be the cause of the higher numbers. Is this possible?

E: Absolutely, It is a longer time span without eating and the liver puts out more sugar. Also if you have wine etc it blocks the use of sugar and can cause a rebounding in the blood sugar level. Are you also less active on the weekend?

Later, as students' knowledge became richer and their model of diabetes became more complete, they tended to share their discoveries in a more confident way, without explicitly seeking a validation. In these cases, it was sufficient for the educator to simply acknowledge students' progress:

S3: I had a yogurt before bed last night, but I realized after I ate it that it was a "regular" yogurt instead of a "lite" one. Too many carbs. And since I had the chocolate earlier in the evening, I probably shouldn't have had anything at bed time. There's so much to learn when dealing with this.

E: sounds like a really good learning experience.

Continuity with MAHI

The main purpose of the technology on this stage of the learning process was to help bring *continuity* into the learning process by promoting an ongoing discourse about students' experiences through contextualized discussion threads. Two particular features that enabled such discourse included 1) *coupling* records of blood glucose values and activities with discussion about these records, and 2) providing *continuity* in records for both the student and the educator.

Coupling

One of the main advantages of MAHI over other record-keeping devices available to the students was its ability to not only capture both blood glucose values and everyday activities and present them side by side, but also to engage its users in ongoing discussion over these records. The importance of such discussion became evident during the first stage of the learning process, when it supported investigation of problems by the students and the educator. During the second stage, visual proximity of records and discussions assisted students in planning and structuring experiments with different types of meals or exercise routines and viewing results of their experiments:

S23: I am trying a green apple b4 [before] bedtime.

S23 (next morning): Blood count this morning was 107, so perhaps green apple is working or perhaps it was 5 hours of sleep. So we will keep trying the apples.

In addition, the capture of rich media records allowed the educators to provide timely feedback to students' experiments:

P30:



BG: 126

E: My recommendation would have been to increase the green beans and decrease the potatoes by 1/4. Then have a snack 2 1/2 to 3 hours.

Continuity

In addition to enabling written discussions regarding the captured data, MAHI preserved these contextualized discussions for future access. This feature helped to preserve continuity in learning and link discrete problems and situations into coherent threads. An example bellow illustrates how a particular learning thread (balancing protein) can develop over the course of several days. In this example a combination of captured records allowed the educator to formulate a recommendation, which was acknowledged by the student and later incorporated into his practice:

P23:



E: Breakfast I would recommend a more substantial protein and not so much carb with that blood glucose level. ie pb or egg or cheese

S23: OK protein in the morning.

A few days later:

P23:



S23: Dear Sugar Queen, Our fare this AM is egg beaters with cheddar cheese and three color bell peppers with a side of peanut butter on one english with a chaser of 12 oz V8. OK on the 2 hour bg when i can remember. Do you think we got the proteins in the mix this morning, LOL?

Oftentimes, the continuous flow of records, annotations and discussions allowed the educator to observe students' progress and provide coaching and feedback when needed:

S30:



BG 110

E: It looks like your proportions are improving? Are you seeing a change in the blood sugars?

S30: Absolutely!

This persistence of records allowed the students to experience learning as a gradual progress with slow but continuous improvement:

"So, it was kind of like education where you're getting to the next level. So we were starting with the basic, you know, what is this and then more of well, how about you added this or this and then finally, we're at the point where we're kind of

dialoging about the um, the orange juice and the... you know, good points and bad points about taking it.” (S9)

Mastery and Withdrawal

A defining factor of any type of scaffolding (Guzdial, 1993), including social scaffolding in the context of learning, is its temporary nature; it is designed to be removed when it's no longer needed. In case of diabetes learning, with time the students were able to demonstrate that they've mastered the new skills or knowledge, firmly integrated them into their own practices and no longer required support, at least in regards to those particular skills:

S3: I've been having a cup of yogurt or a glass of milk (last night was yogurt) right before bed. It certainly seems to be helping, and I'll certainly continue with this. I'm surprised that I haven't read anything on the internet about a bed-time snack as a way of stabilizing morning BG readings, since it works so well for me. Thanks for bringing this to my attention.

Metacognition with MAHI

Earlier I have discussed the importance of maintaining a *persistent history* of contextualized discussion threads, which included automatically captured blood glucose values, records of activities made with the mobile MAHI application and on the website, and verbal and written discussions captured with mobile MAHI and on the MAHI website. In addition to adding coherence and continuity to the learning process, this history, which was persistent on each individual's website, had an additional benefit of allowing students to observe the progress in both their blood glucose readings and their

understanding of their disease, thus inspiring and contributing to *metacognition*. The excerpt below illustrates one account of such metacognition, triggered by a relatively simple question from the educator:

Captured BG: 126 [down from 140s at the beginning of the study]

E: How do you feel about this number?

S3: Interesting question. I feel good about it in that I think that it shows that I am beginning to get control of my BG numbers. I can see the relationship between the choices that I make each day and the test results that I am seeing. The numbers are coming down, but I would like to see them lower still. I will continue my exercise regimen, and will continue to be more selective in what and how much I eat. I'm hoping that as I continue to lose weight, the numbers will continue to drop. In looking over the numbers on this page, I see that only 2 weeks ago my morning numbers were often in the 140's, and now they are in the 120's - 130's. That makes me feel good.

Because the participants could see changes in their own thinking about diabetes, their approach to solving problems and their attitude to self-care, they were able to realize and appreciate their own mastery, thus contributing to their growing self-confidence. The excerpt below shows student's transition from relying on educator's judgment to more confidently sharing his own conclusions. This transformation evident in the qualitative data is consistent with the quantitative measure of transformation of individuals' locus of control and further supports this finding.

First week of the study:

s3: my morning bg levels often seem higher on the weekends. i usually sleep a little longer on sat. & sun. (~ 8 1/2 or 9 hours instead of the usual 8), and i was wondering if this could be the cause of the higher numbers. **is this possible?**

e: absolutely, it is a longer time span without eating and the liver puts out more sugar. also if you have wine etc it blocks the use of sugar and can cause a rebounding in the blood sugar level.

Last week of the study:

s3: i had a yogurt before bed last night, but **i realized** after i ate it that it was a "regular" yogurt instead of a "lite" one. too many carbs. and since i had the chocolate earlier in the evening, i probably shouldn't have had anything at bed time. there's so much to learn when dealing with this.

e: sounds like a really good learning experience.

Comparison with Control Group

As I mentioned earlier, the analysis of data collected with MAHI indicated that much of the learning evolved around solving diabetes-related problems specific to each individual. These joint troubleshooting sessions formed the basis for learning through cognitive apprenticeship with MAHI. In this section I will contrast this with my observations of learning in the control group.

To elucidate the difference in learning between experimental and control groups, I transcribed a selection of the 80 2-hour classes recorded during the study. I chose the

selection to fairly represent four distinct class tracks, each taught by a different instructor (or a combination of instructors) and each taught at a different time (morning/afternoon/evening), which greatly affected class demographics (for example age) and, consequently, its dynamics. In addition, I sampled the records throughout the 4 weeks of the study to account students' increased familiar and comfort with the program. I selected eight classes (10% of all classes; two of each class tracks with a fair mix of class progress) for time coding to find the proportions of class time allocated to the lecture and to the questions and discussion. I then selected a separate set of 13 classes with a fair mix of class tracks and progress and coded class transcripts for content, distinguishing the types of questions students asked and the topics of the discussions.

This analysis confirmed that to a large degree the classes followed a lecture style; less than 20% of the two hours were dedicated to questions and discussion and over 80% to educator's presentation of the class material. Moreover, the majority of the questions and discussions during classes (over 75%) were dedicated to clarifications of what was presented during the class or general questions regarding diabetes. Moreover, the majority of the 25% of personal questions were put forth by a small set of individuals who clearly dominated the discussions in their respective classes. Such uneven class participation created some tensions among students who felt somewhat annoyed at their too active classmates.

“You know, I’m not a very patient person, when it comes to someone who wants to beat something. Um, someone who wants to beat something and keep telling me about their problem... their problem... their problem. You know, that’s what I had to listen to, and I wasn’t very happy about that. I think that comes with the

territory.” (S10)

This virtual lack of discussions regarding personal problems and issues for the majority of students meant that the classes helped them to acquire general knowledge of diabetes-related issues, but they contributed little to their skills of reflective analysis and solving diabetes-related problems. Not surprisingly, both experimental and control groups showed significant improvement in their general understanding of diabetes, as measured by the Diabetes Understanding Questionnaire. However, MAHI users were significantly ahead in areas concerned with unique personal improvements, whether actual behavioral goals or in their attitude toward the disease.

To further demonstrate the limitations of learning in the control group, consider the following example from the transcripts of classes:

S25 (a question during the class): My bedtime readings are always high, around 200 and I don't really know what the reason is.

If this question was a part of MAHI discourse, the educator probably would have already had records of students' activities that could have highlighted potential causes of the problem, for example a usual time of evening meals. If there were no such records, or no indication of potential reasons in the data, the educator could use her knowledge of what may possibly lead to high bedtime readings to formulate hypotheses and test them through a written discussion with the student. Since MAHI preserves all the discussions, the questions of the educator would have been available to the student as a reminder. If the student chose to engage in the experimentation, the educator would have been able to monitor the student's progress and provide the necessary feedback.

As it were, without MAHI support, this question led to some relatively generic questions from the educator, until the discussion was interrupted by questions from other

students. As a result, there remained no traces of the educator's problem solving strategies available to the student, no evidence of experimentation and, to the best of my knowledge, no coherence in solving this problem – the student never mentioned the problem again, even though it most likely remained unresolved.

Cognitive Apprenticeship in Ubicomp

In the Introduction to this chapter, I referred to Cognitive Apprenticeship as a framework for understanding the style of learning that emerged during MAHI deployment studies. But CA can be more than just a metaphor; my studies showed that it could be a viable model for engaging individuals with diabetes with health monitoring applications and enhancing more traditional diabetes education.

I want to begin by distinguishing CA in health monitoring from other approaches to engaging health care professionals in computing technologies for chronic disease management. The most traditional among these approaches is viewing the expert clinician as a case manager and the receiver of the collected data, an approach common for the majority of telemonitoring applications (Bashshur *et al.*, 2000). In this model, individuals with diabetes use a variety of medical monitoring devices to capture indicators of their health with a supervision of a remote health care professional, most commonly a certified nurse. The nurse then reviews the results of individuals' monitoring, and shares with the individuals her conclusions and their implications for the future care. This approach, consistent with the traditional health care model, further promotes patients' disengagement from the monitoring and their reliance on powerful others to form the judgments regarding their health and health care.

CA is also different from the more straightforward diabetes education, as I hope became evident from the comparison between the control group and the experimental group. In the more traditional style of instruction, the educator delivers teaching materials and helps students understand the new information. In CA, the educator enacts her own problem-solving skills, thus exposing the students to her own model of diabetes. Collins, Brown and Newman (1991), who pioneered the Cognitive Apprenticeship approach, argue that the more traditional schooling tends to produce knowledge that is more inert, less transferable between problems, and less available for novel situations and contexts. In contrast, CA leads to knowledge that is more grounded, active and usable. “In some cases,” writes Collins (Collins *et al.*, 1991), “knowledge remains bound to surface features of problems as they appear in textbooks and class presentations.” In contrast, in CA, students observe how experts apply their problem-solving skills to a variety of problems and situations, leading to the more nuanced understanding of the problem space. In addition, CA exposes students not only to the ready-made optimal solutions to the problems, as would be the case with the more traditional instruction, but also to the more realistic trial and error strategies utilized by the experts. Watching experts make mistakes, pursue erroneous paths, and iterate on the solution not only contributes to students’ learning, but also builds up their confidence in their own abilities.

The analysis of interactions between students and educators in the context of the control group show that enabling CA within the traditional diabetes education is a considerable challenge. Limited time for discussion, the general tendency for discussion time to focus on clarification of class material, and uneven participation of students in class discussions make learning driven by solving specific diabetes-related problems

impractical, if not impossible. As a consequence, while students' general understanding of the physiology of the diseases and general approaches to its management improved, their ability to engage in solving specific problems remained limited. MAHI studies showed that computing technologies can remove some of the barriers to introducing cognitive apprenticeship as a model in diabetes education and as an approach for engaging individuals with health monitoring applications. Most importantly, shared access to health and activity data and the opportunity to discuss the records in a written form exposed the students to the experts' problem-solving strategies. In addition, the asynchronous style of communication removed some of the social barriers to a more proactive students' engagement by lowering the intrusiveness of the interactions and, as a consequence, reducing the burden for the educator. MAHI users simply went about their lives making occasional records, and the educator made comments on the captured data at her convenience. All these features allowed individuals with no experience in analysis of health-related data gain sufficient confidence to approach the task and, with time, to be able to engage in independent and successful problem-solving.

Lastly, I wanted to conclude my discussion of CA in the context of diabetes management with some notes on its general applicability to health monitoring applications. The main property of CA is its reliance on an engagement of a human expert. This approach has obvious limitations: the expert may not always be available, the expert's time might be limited, and students' progress largely depends on the personality of the educator and her own problem-solving skills. There is, however, an opportunity to address this limitation with emerging technologies that take advantage of advanced natural language processing and machine learning algorithms to simulate

conversational style of human experts. These conversational agents are gaining popularity and general acceptance in health care and, specifically, in patient education and instruction (Bickmore *et al.*, 2009). The initial review of the MAHI educator's approach to formulating questions for the students shows that there is some consistency to her method, which renders conversational agents a viable alternative to the human expert.

Conclusions

In the previous chapter I demonstrated that MAHI helped individuals achieve their personal diabetes management goals and increase their sense of control over their disease, as indicated by their adoption of the Internal Locus of Control (Wallston *et al.*, 1976). Further examination of the origins of these changes indicated that the ability to capture annotation, engage in contextualized discussions threads, and retain a persistent history of records contributed to the success of the learning process. It also highlighted a number of opportunities to improve and further extend the MAHI design, which I discuss below.

Capture and Annotations

One of the most successful design decisions in MAHI was in regards to the redundancy of media for capturing annotations (voice and photographs on the phone and written notes on the website). This redundancy allowed students to choose a media most suitable to their own lifestyle and preferences. Some of my participants preferred the immediacy of voice notes; others felt that writing on the website better agreed with their sense of privacy, which was more important than the time delay it caused. Similarly,

many of the participants valued the richness of photographs, while others felt that simple written records were sufficient to capture the necessary information:

“Because, I don’t know about the other women, but what I think is we have kind of repertoire of what we have, what we do, where we go, what we eat. I’ll write “green bean stew.” I know that comes with a cup of rice. I may put a quarter cup or half cup of rice. I know usually what goes with the meal that I prepared.” (S24)

However, the richness of the records greatly impacted the educator’s ability to provide coaching and the nature of this coaching. In cases of sparse or short textual records the educator had to ask many clarification questions, for example regarding meals’ ingredients and their proportions. On the other hand, for those records that included rich media, the educator could formulate questions that required more contemplation and judgment from the students:

P30:



E: how many carbs do you think you have eaten with this meal??

S30: I actually ate half of the rye/whole wheat bagel and used the two pats of butter. I think (thought) I was within my 2 -3 carb breakfast allocation.

On a more negative side, this redundancy in media at times led to breaches in user expectations. For example, using the phone for annotations created an expectation for an immediate response from the educator, as is common in a regular voice exchange, which was not always possible in MAHI. In this regard, web-based annotations were more in accord with the asynchronous nature of the discussions.

Contextualized Discussion Threads

Another successful design decision was to visually couple records of BG values and activities with written discussions about these records. This mapping provided rich context for such discussions. However, both the students and the educator desired a more extended support for the discussions themselves. Such features as indication of turns, time of posts and order of posts could better support multi-turn conversations. To compensate for the lack of these features in the current MAHI design, the participants invented their own ways of indicating turns, for example by using special symbols (“////”). I hypothesize that Instant Messaging-like design of discussion flow would provide the necessary support.

In addition, while web-based discussions were deemed appropriate as supporting students’ learning, they lacked the immediacy necessary to provide assistance at the time of making decision. To address this limitation, the phone could be used as a dual-purpose device for both capture of records by students and as a mechanism for the more timely delivery of messages from the educator.

Persistent History

One of the more controversial design decisions in MAHI was to display all the records for a participant in a table adding each newer record as a row to the bottom of the table. This feature essentially forced the participants to scroll through all their previous records before viewing the new ones. Many comments made by the participants during the interviews showed that this somewhat forced review of the entire previous history did lead to valuable insights; the students often noticed certain salient records or interesting

patterns while scrolling through the records. At the same time, with the increase in the number of records (at times beyond 100), the scrolling became cumbersome and its cost likely outweighed the benefits of reviewing a history of records. A more elegant solution would have been to provide a condensed presentation of the record history following one of the mantra of Information Visualization, overview and detail (Shneiderman, 1996).

CHAPTER 7

DI-TAG: REFLECTION IN A COMMUNITY OF INDIVIDUALS WITH DIABETES

Introduction

In the previous chapters I discussed the trajectory of my efforts in designing ubiquitous computing applications that help individuals with diabetes reflect on and learn from their past experiences. The first two applications, CHAP and MAHI, and their deployment studies indicated that including features that engaged individuals in the capture of diabetes-related data and monitoring of their health inspired reflection and learning. These features included the ability and encouragement to annotate the captured readings at the time of capture, share and discuss the readings with the educators and review a persistent history of the captured readings coupled with annotations and discussions. Combined, these features helped individuals to achieve their personal diabetes management goals. Even more importantly, they inspired the participants of my studies to embrace a more proactive stance towards management of their disease, indicated by their adoption of the internal locus of control.

However, there remained a number of questions that still required additional investigation. For example, MAHI was designed for a very specific environment and context of use—as part of the diabetes education program. This environment had a number of salient features that impacted the way MAHI was used by the participants of the study, and, consequently, impacted my analysis and interpretation of their experiences. First of all, MAHI users were newly diagnosed individuals, who had little understanding of diabetes, and were, consequently, open and eager to receive any

assistance that was available to them. In addition, MAHI users attended diabetes education classes at the time of the study. These classes significantly contributed to individuals' overall experiences, as was indicated by the results of the quantitative assessment of MAHI: both experimental and control groups showed significant improvements in their understanding of diabetes and their diabetes management practices.

To extend my findings beyond the specifics of MAHI deployment studies, I have selected a new deployment environment, which differed from that of MAHI along both dimensions I described above. New study participants were recruited among attendees of diabetes support groups, who had considerable experience with diabetes and who did not attend formal classes. To better understand the unique needs of this particular group, I conducted a qualitative study of diabetes support groups relying on such techniques as observations of group meetings and interviews with group members. This study showed that to appeal to this group, the application needed to be modified and adopted. For example, while MAHI was specifically designed to support one-on-one communication with the educator, one of the main strengths of the new deployment environment was an availability of a community of practice. Consequently, there was an opportunity to take advantage of communal support and community-wide communication. Because in a community setting articulation of ideas and opinions becomes of an increased importance, the new deployment environment provided an opportunity to further elaborate on the notion of articulation and explore design features that facilitate articulation of opinions. Consequently, my main goals in the design of the new application, Di-Tag, were to explore new ways to further promote articulation in the

context of a community of practice. Specifically, Di-Tag utilizes *social tagging* mechanisms to allow a community of individuals with diabetes share and analyze their health-related data and *collaborative writing* to help them formulate their emerging understanding of the different aspects of diabetes care. I deployed Di-Tag with participants of face-to-face diabetes support groups hosted by the Regional Diabetes Education Center in Dover, NJ. Eight individuals volunteered to participate in the eight-week deployment study. The results of the study showed that collective classification of the captured records alerted users to the multiplicity of possible interpretations and helped them enrich their understanding of these records. At the same time, it demonstrated that introducing a community of individuals significantly changed users' perception of the application and their expectations of its capabilities. Instead of seeing it as a health monitoring application that assists with solving problems, the users perceived it as a social networking application and expected assistance with identity management (for example through creating profiles) and community building (for example through creating lists of friends).

In this chapter I present concepts and related work not included in the general background chapter, discuss the results of the exploratory study of diabetes support groups, describe the Di-Tag's design and the results of its deployment study. The deployment study of Di-Tag was more limited and smaller in scale than the MAHI study, which prevented me from generating broad conclusions or from collecting sufficient data for quantitative analysis. However, it did allow me to further refine my understanding of articulation and to structure the research space for future work.

Background

Health Communities

In the previous Chapters, I described examples of technologies that attempt to enhance individuals' reflective thinking by supporting capture of relevant experiences in the past and allowing access to these records in the future. In this Chapter, I will shift my focus from supporting individual reflection to mechanisms and technologies that view reflection as a social and collaborative process.

Health care researchers and practitioners have long noticed the importance of emotional support in times of distress, often associated with illness, and, especially, with long-lasting chronic diseases. To address this need, health care centers often host meetings of support groups, in addition to the more traditional clinical treatments. These groups help individuals cope more effectively with diseases, and often lead to reduction in stress and loneliness (Blanchard *et al.*, 1995, Thoits, 1986).

In recent years the advantages of emotional support became available to an increasing number of individuals through online health support groups. According to the *Pew Internet & American Life: Online Life Report* (2006), fifty two million American adults researched a disease or a medical condition on the Internet. As of September 2008, Yahoo! Groups included over 300,000 various groups in Health and Wellness category, Support groups being the largest subcategory with close to 40,000 registered groups. These groups vary in the design of their technological environments and social structures. Consequently, the patterns of communication vary between different groups. For example, Wright (2000) studied messages from forums within one of the established and

longest-running support community for senior adults, SeniorNet. He identified three main categories of messages:

- Promoting community support (messages saying that the community was a great place to be)
- Advice disguised as self-disclosure (explaining how one deals with a problem)
- Shared life events (describing events in daily life)

In the course of the study I observed that the intensely personal stories the participants shared with each other tended to fall under one of the following general categories, similar to the ones identified by Wright:

- Raising problems or issues—when participants shared puzzling experiences seeking possible explanations;
- Sharing discoveries—when participants shared new experiences seeking confirmation and also raising their status in the community; and
- Sharing challenging personal experiences—when participants undergone difficult medical procedures and were seeking emotional encouragement.

In addition, many of the conversations followed a similar pattern. They started with a participant sharing a personal story, most commonly describing how a challenge encountered in the course of daily activities led to a discovery. Other participants in the group continued the conversation by adding their comments, and sharing relevant experiences and discoveries. The group together reshaped and modified the original story until it reached the state of a universal agreement, and incorporated various experiences and opinions. One of the design goals of Di-Tag was to recreate the experience of reshaping of personal discoveries through discussions with a support community.

While researchers generally agree on the positive effect of support groups (Wright, 2000), some argue that the results of the studies conducted so far are generally inconclusive (Eysenbach, 2004). More research is needed to further understand the impact of computing mediation on the benefit of health support groups.

Social Tagging

One particular mechanism for a community of individuals to converge on a shared opinion that became increasingly popular in the recent years is *social tagging*. The main premise of the approach is in allowing individuals to assign free-form key words, or tags, to items of interest and in storing thus annotated items in a shared repository. Examples of such items include digital documents, such as files, images, or URLs. When multiple people use identical tags for items, aggregation of such tags leads to the emergence of a user-created categorization scheme, known as a “folksonomy” (Vanderwal, T. 2006). Tags present an alternative to the more traditional way of creating a categorization scheme, or ontology—by involving an expert. Multiple researchers see such expert-created ontologies as having a number of limitations. For example, Clay Shirky (2004) argues that expert-created taxonomies are not capable of responding to the changing interpretations of the states of the world. In addition, since categories must be discrete and limited in number, they inevitably result in loss of data, when items fall in-between established categories. In contrast, social tagging is flexible and fluid, continuously responding to the changes in the understanding of the world. In addition, it allows for emergence of multi-layer taxonomies, from the more general categories, to the very low-level idiosyncratic ones, with no loss of data.

In recent years, there emerged several popular services that utilize social tagging mechanisms for a variety of stored digital content types. Some of the well-known services include:

- Flickr.com (<http://www.flickr.com>), which allows individuals to store and tag personal photographs;
- Del.icio.us (<http://del.icio.us/>), which allows to store and tag favorite websites;
- YouTube (<http://www.youtube.com>) for annotating and sharing videos;
- Technorati (<http://www.technorati.com>) for aggregating annotated blogs; and many others.

The growing number of services incorporating social tagging mechanisms inspired investigations by researchers in both HCI and social sciences. Marlow *et al.* (2006) identify a number of design dimensions for social tagging services, which include:

- Tagging rights, or who is given tagging privileges of what the stored items;
- Tagging support, or whether or not users are provided with suggestions or blind tagging;
- Aggregation model, which include bag or set;
- Object type, such as textual and non-textual;
- Source of material, or where the items for tagging are coming from;
- Resource connectivity, by links, groups, or none; and
- Social connectivity, again by links, groups or none.

Many of the systems I listed above vary in their design choices along these dimensions.

One of the important abilities of social tagging systems is to communicate the emergent categorization scheme to the users. A common mechanism for accomplishing this is *tag clouds*. Tag clouds are visual representations of all the tags collected in the system, with such visual parameters as text, size, and spatial orientation used to represent relative popularity or recency of tags' usage. An alternative depiction of a tagging vocabulary is through a list of sorted tags; these lists could utilize similar visual mechanisms (font size) to draw users' attention to more popular or recently used tags.

While many of the existing studies of social tagging mechanisms focus on investigating existing commercial applications and services, other researchers incorporate social tagging mechanisms in novel applications where finding items of interest is of particular importance. One such domain is collaborative software development. Storey *et al.* (2006) describe TagSEA – an application that combines waypoints with social tagging to allow developers to annotate common bugs.

Most of the systems I described so far utilize tagging mechanisms to simplify access to items of potential interest to users. For example, flickr.com allows individuals to find photographs of potential interest by searching for relevant tags. At the same time, researchers argue that social tagging systems can help users achieve shared understanding of items of interest (Shirky, 2004). In my work, I am particularly interested in this aspect of social tagging systems. Specifically, I argue that social tagging can serve as a mechanism for social validation and confirmation of individual discoveries in diabetes.

This particular application of the social tagging mechanisms imposes certain restrictions on the appropriate design dimensions. For example, and as is the case in such applications as TagSEA, it is important that users favor reusing tags already existing in

the shared vocabulary, whenever appropriate, to creating new tags every time. In addition, it is particularly important that users are able to maintain awareness of the overall tagging vocabulary, and, most importantly, relationships between tags. These considerations impacted design choices for Di-Tag.

Collaborative Writing and Wikis

While social tagging systems can facilitate the emergence of shared viewpoints and opinions, arguably, they fall a step short of creating new knowledge. Tag clouds and tag lists may lead to the emergence of implicit understanding. However, this understanding requires additional reflection, articulation and integration for transformation into knowledge. One way to enable the necessary reflection and integration is through writing (Bereiter, 1987, Britton, 1975). Just as writing activities can help students in a classroom environment, they can help learners with diabetes achieve new levels of understanding by reflecting on records of their past experiences.

One approach to writing that has particular relevance for my research is mediated collaborative writing. An example of a vibrant social community engaged in mediated collaborative writing is Wikipedia. Wikipedia is an online encyclopedia built on wiki technology that allows willing volunteers to engage in collaborative writing of articles. The success of Wikipedia, while surprising even to its creators, is undeniable. As of September 2008 it contains over 7 million articles in over 200 languages and is still growing; it is not uncommon to find references to Wikipedia articles in press and other media (Lih, 2004).

The democratic spirit of Wikipedia is in a close accord with the social tagging approach. From its inception, Wikipedia allowed individuals to engage in creating and

editing articles without registering, or otherwise applying for editing privileges. While there are more recent restrictions to the editing policies, the general spirit of collaborative writing remains intact.

As an encyclopedia, Wikipedia primarily allows individuals to engage in the construction of articles on topics of general knowledge. Since editors often conduct extensive research that informs their writing (Bryant *et al.*, 2005), one could argue that even for the editors the writing process leads to learning and not just expression of pre-existing knowledge. However, many of them engage in writing because of their pre-existing expertise in particular topics. In the context of diabetes learning, I projected that individuals might approach diabetes-related topics with no pre-existing knowledge. In contrast to writing in Wikipedia, I expected individuals' understanding of diabetes-related facts to emerge as a result of their engagement in writing. As a consequence, individuals might need an access to the empirical basis that could help them formulate their conclusions, expressed in writing. To support this need, Di-Tag combined social tagging and collaborative writing mechanisms in one application. In this case, individuals engaged in learning by collecting and annotating facts about diabetes, gathered through their personal experiences. Viewing this shared annotated repository allowed individuals to compare their experiences and discoveries with those recorded by other people. Once collected information reached certain level of richness, and the tagging scheme demonstrated a certain level of convergence in opinions, the individuals could collaborate on articulating their shared understating in writing.

Studying Diabetes Support Groups

Settings

The support group observed during this study was sponsored by the ADA (American Diabetes Association) certified Diabetes Education Center in Dover, NJ. The center employs a number of expert diabetes educators, including registered dietitians and registered nurses that deliver diabetes education and facilitate support groups. Diabetic patients are referred to the Centre by their physicians and enroll into classes that consist of 4 two-hour sessions delivered over the course of 4 weeks. The classes are conducted throughout the day to accommodate different schedules of retired and still employed individuals. The classes cover a number of diabetes-related topics, such as general diabetes physiology, methods for monitoring diabetes and introduction to glucometers (blood sugar monitoring devices), nutritional education and the ability to calculate nutritional value of meals, and diabetes management techniques. Each student receives personal consultation with a dietitian, who develops a personalized diet plan, and a nurse who assesses the general diabetes awareness and the coping level. The students receive a personalized follow-up session 8 weeks after the classes to assess the change in their attitudes, coping level and health state.

The support group I observed in my study included individuals with type 2 diabetes, who were not using insulin (a hormone used to regulate the blood sugar levels; insulin groups met separately). The number of people in the group varied between 8 and 15, all participants above the age of 40, most above 50, with a relatively even male/female split. The length of participation in the group varied widely, with the most senior tenure of over 8 years, and several newcomers present at every group meeting. An

expert dietician, trained in moderating support groups attended each meeting and helped to facilitate the discussions in the group. The group met on a bi-weekly basis.

Method

Due to the sensitive nature of the discussions, no video or audio capture was used. As an observer, I participated in all group meetings over the course of the study, capturing observed activities and discussions, and attempting to introduce minimum disruption into the dynamics of the group. The captured observations were annotated and coded after each session.

Findings

Discussion Topics

To a degree, the discussions within the support group mirrored the curriculum of the diabetes education classes and were relatively common for the diabetes support groups. Below I describe the most common topics of the discussions in the group.

Symptoms

One of the dangers of diabetes is a common lack of observable symptoms. This reduces the urgency of rigorous adherence, and may potentially lead to the development of complications. One of the common topics for the group was a discussion of how to recognize common symptoms of hyper- (abnormally high) or hypo- (abnormally low) glycaemia and how to choose an appropriate compensation strategy.

Nutrition

The common themes related to nutrition included nutritional recommendations with explanations, ways to calculate nutritional value of meals with practical exercises, and ways to alter individuals' diets based on blood sugar readings. Another of the recurring themes was the discussion of misleading food labels, such as fat-free cooking oils, with fat calculations based on tiny serving sizes, commercial advertisements for popular low-carbohydrate foods, and dangerous popular diets.

Supplements/vitamins

This theme included conversations regarding the mechanics of the physiological functioning of supplements and vitamins; recommendations for who should take them and who should not, as well as dosage and possible side effects.

Medication

These conversations included reviews of medication types and their physiological effects, common ways to combine medications, dosage and potential side effects.

Medical procedures/Treatments

In many cases, participants shared their personal experiences with particular medical procedures and treatments, such as cholesterol screening. Oftentimes, the educator took these personal stories as an opportunity to educate the rest of the group about the procedure.

In the rest of this section, I summarize aspects of the support group that were crucial to the successful functioning of the group, yet may present challenges to augmentation with computing.

The Importance of Observable Similarities and Social Ties

At least 50% and often more of the support group discussions were dedicated to topics unrelated to diabetes or diabetes management. Some of the topics recorded during my observations included:

- Baby names (after one of the participants announced a newborn grandson to the group and shared the pictures)
- US wars (Vietnam, both Iraq wars, after one of the participants came wearing combat boots)
- Social development of New Jersey counties from the turn of the century (all the participants live in NJ)
- Travel and places visited (after one of the participants brought a travel guide to the group)

In many cases these conversations seemed to have sprung from the observable similarities between the participants, such as age, marital status, and their overall state of health, or from observable cues, such as the travel guide. Because of the relatively high variability of the participants, these visual cues were especially important in engaging newcomers in the discussions, and helping them find ways to identify themselves with the more senior group members.

The Role of the Facilitator

The group I observed in the study was moderated by the registered dietician trained in facilitating support groups. The facilitator played a number of different roles, including:

- Ensuring an easy entry into the group for the newcomers, and an easy resumption for participants who were absent for extended periods of time;
- Providing expert opinion, teaching, and personal consultations;
- Facilitating group conversations, proposing new topics, including less vocal group members in the conversation, and converging conversations to a single thread; and
- Providing a contact point for group members for interactions outside of the group settings.

On a more subtle level, the facilitator's tasks included encouragement and motivation and, perhaps most importantly, a non-judgmental, yet professional opinion. I observed participants sharing with the facilitator experiences and opinions they were not likely to share with their doctors, such as deviations from the prescribed medication schedule, or from the diet. The facilitator first of all remained a trusted person, laughing at missteps together with the group, joining discussions about favorite unhealthy foods, and sharing personal diabetes experiences, and only secondarily played the role of an expert who can provide a professional advice. In fact, the personal ties with the moderator were so strong that the group stayed in touch with the previous facilitator, who relocated to Florida.

The Flexible Structure of Conversations

The lively dynamic flow of the conversation depends on the participants' ability to stay engaged and personally interested in the topics discussed. I noticed a high variability of different conversational structures emerging throughout the meetings; a short list of these includes:

- Single-threaded, public conversation, with one topic presented to the group by the facilitator, or discussed in turns by different participants;
- Multi-threaded, semi-private conversations, with different topics discussed concurrently by smaller groups of participants; these usually sprung off of the single topic of sufficient interest, when everybody wished to contribute to the discussion;
- Multi-threaded private conversations, with topics discussed privately by two or three participants, occasionally with the facilitator, and often while the rest of the group was engaged in the single-threaded discussion

During support group meetings, the conversational structures changed rapidly and fluidly, with a single topic diverging into many semi-private conversations, and converging back into a single, but different topic in a matter of minutes. An important factor contributing to such rapid and flexible flow was the participants' and the facilitator's ability to monitor ongoing conversations. This allowed the participants to choose when to start a new conversation with a neighbor, or when to join an existing one. It also allowed the facilitator to choose which topics to support, and when to bring multiple conversations back to a single topic.

Family Involvement

Since genetic inheritance is one of the common causes of diabetes, most of the support group participants had family members affected with the disease. Even those not suffering from the disease directly, were involved in diabetes care. Presence of families was visible through all the group sessions I visited. Occasionally, family members accompanied the participants to the sessions and actively participated in discussions. In many cases participants raised questions about the experience of their family members:

“My dad is on insulin, so I was just wondering what the best type of insulin is and how you go about selecting it.”

In one case, a question about the medications taken by a participant’s father was resolved by engaging him in an extended discussion with the facilitator on the cell phone, to the amusement of the rest of the group. The participant later commented: “I wish I had free long distance, so that he can participate all the time”.

Coordination of Participation in Local Diabetes Events

Because all of the participants were collocated in the neighboring areas, a large portion of the group discussions was spent coordinating participation in the events dedicated to diabetes education and organized by different local communities and organizations (malls, conference centers, community centers). These included cooking classes for diabetics, diabetes EXPO, and demonstrations of diabetic chefs, among others. A portion of each session was dedicated to the discussion of the upcoming events and logistics of the group participation, such as carpooling, fees and tickets.

Personal Consultation

Often, in addition to participating in a common discussion, participants engaged in personal consultation sessions with the facilitator. These included review and discussion of the recent blood-sugar readings, doctor’s recommendations, such as medication types and dosage, supplements dosage and combinations, individual nutritional needs and preferences, and doctor references, among others. These consultations varied in the degree of group participation. Sometimes, participants engaged in consultation with the facilitator in front of the entire group. In these cases the facilitator tried to present an answer in a relatively general form, to make it relevant to

the others in the group. Most commonly, however, consultations happened at the end of the meeting; the participants often formed a line to approach the facilitator with personal questions.

Sharing Experiences and Negotiating Meaning

One of the advantages of participating in a support group is the ability to learn from the experiences of other participants and from the stories shared by the facilitator. Even if not immediately applicable, these stories can warn individuals of potential dangers or bring certain possibilities to their attention. Participants continuously shared new personal experiences, discussing and sympathizing with the stories, while contemplating their applicability to personal cases. Frequently, these experiences happened outside of the group settings and, occasionally, in the relatively distant past. And one of the most important aspects of participation in face-to-face support groups was participants' ability to formulate their understanding of their own experiences in light of feedback and comments from others, and negotiate this understanding with others. This last aspect of diabetes support groups, their ability to help individuals formulate, articulate, and negotiate their understanding and experience became the basis for the new computing application, Di-Tag.

Di-Tag

The findings of the study presented an opportunity to adopt MAHI design for the new user group and new usage scenario. As I suspected, formulation and articulation of opinions became one of the main challenges in the context of diabetes support groups. Consequently, the main focus of Di-Tag was on exploring features that helped with this challenge. In particular, I developed an approach that took advantage of two known

collaborative mechanisms, social tagging and collaborative writing. Social tagging is a popular approach to help a community of individuals to create an aggregated repository of experiences for reflection, and negotiate the meaning of these experiences.

Collaborative writing, for example, supported by wikis, can help individuals to converge on a shared opinion through a series of revisions by different members of the community.

In the context of diabetes management, I combined these two approaches in my new application, Di-Tag, to allow a community of individuals with diabetes to engage in sense-making and learning through shared reflection.

Design

Di-Tag was designed as an extension of MAHI and utilized similar capture mechanisms on a cell phone, with a number of important differences. Because the focus of my explorations was on features for articulation, I simplified other aspects of the applications. For example, Di-Tag only functioned as a diary, without the experience sampling mechanisms. In addition, in order to make it possible to deploy Di-Tag in a larger community, I excluded the custom hardware devices and replaced them with the manual entry of the captured blood glucose values in the phone. At the same time, I have expanded on the features for articulating and communicating opinions.

Users initiated interaction with Di-Tag by indicating their readiness to make a record of an activity. At that time, they were prompted to enter an optional reference blood sugar value, in case they wished to capture blood sugar before and after the activity—a common practice for individuals with diabetes. Once the value was entered, the individuals used the phone's camera to capture relevant images to describe the activity, and audio recording to add voice comments. In the next step, they were asked to

describe the activity using keywords or tags, by either selecting from the list of available keywords, or by adding their own to the list. The list of available keywords included all the tags entered by all the individuals using Di-Tag, maintained in a server-side database. Each phone periodically synchronized the local copy of the tags with the central copy to ensure the inclusion of the most recently added tags.

The next step of the interaction happened two hours after the initial recording to allow the individuals to assess the impact of the captured activity on their blood glucose (two hours is the usually recommended period of capturing post-activity blood glucose). At that time, the phone reminded the individuals of the opportunity to assess the impact by a short ring. The users were prompted to enter an optional post-activity blood glucose value. After that, they were able to review the records of the activity (pictures and/or audio), and the calculated difference between the pre- and post-activity blood glucose values, if both of these were captured. At that time, the users were able to add another set of keywords to the activity.

There are several design choices I made for Di-Tag that I would like to explain in more detail:

1. When using social tagging mechanisms, it is important to facilitate reuse of the existing tags by many users to allow for the emergence of a shared vocabulary. There are many approaches to such facilitation, for example tag recommendations based on the nature of the item (Marlow, 2006). In Di-Tag, individuals needed to review the list of existing tags before creating their own. This design was meant to achieve several goals: on one hand, it could give individuals unfamiliar with tagging mechanisms examples of how others were describing their activities. On the other

hand, it could help to reduce the occurrence of slight variations in otherwise similar tags.

2. Di-Tag allowed individuals to enter activity descriptors, or tags twice, at the time of activity capture, and after the two-hour interval. This approach was meant to allow individuals to enter different types of tags. For example, I hypothesized that at the beginning, when capturing a meal, they may choose the following set of tags:

“Breakfast, eggs, bacon, coffee, weekday”

After the two-hour period, especially if they captured the pre- and post- activity blood sugar values they might choose tags that are more descriptive of the activity’s impact on their blood sugar, rather than of the activity itself. Examples of such tags could be:

“Excellent choice, 120 after, 10 delta”

The outcome of such choices for the tagging vocabulary is the building associations between tags describing activities, and tags describing their impact on blood sugar values, for example between the two sets of tags

The second component of Di-Tag was the website that allowed individuals to review the collected vocabulary of tags and corresponding records, review the aggregated associations between tags and engage in collective writing about the underlying activities. The participants were able to choose screen names different from their real names, to further facilitate free exchange of experiences and opinions. The front page of Di-Tag included a number of usual features of wiki sites, such as a sandbox, and presented a collection of existing tags in a tag cloud. Each tag was associated with a wiki-page, which presented all the activities that were associated with the tag, and all the other tags

that were used together with the selected one. Selecting a new tag from the list of associations allowed individuals to link tags and view all activities that were described using the selected two tags together. The individuals will were able to view the details of the recorded activities, or continue exploring different associations between tags. Finally, users were able to add descriptions to each tag-page in the usual wiki collaborative writing style. Screenshots of the Di-Tag website are included in the Appendix G.

Di-Tag Usage Scenarios

To further illustrate the anticipated usage of Di-Tag, in this section I present two short usage scenarios.

Usage Scenario 1: Novice User

Laurie just started using Di-Tag and is not sure yet what she should do to make the application useful for her. She is currently experimenting with different brands of cereal and she decided to use Di-Tag to help choose the best one. First she went to Di-Tag website and found the tag “breakfast”. From there she could see all the other tags that were associated with breakfast. She noticed that “toast” and “peanut butter” were quite popular and made a mental note to try it next time. But now she is interested in cereals, so she found the tag “cereal” in the list of related tags (see Di-Tag screen shots in the Appendix G). She noticed several brands that “cereal” tag was related to and selected “Special K” from the list. The description of the “Special K” on the tag’s page expressed general disappointment with it; the contributors generally noticed that it was raising their blood sugar beyond the desired level. Laurie decided to stay away from the Special K cereal and continued her exploration of other brands.

Usage Scenario 2: Experienced User

Jim has been using Di-Tag for a while and his new quest is bagels. Bagels are Jim's favorite breakfast food and he is determined to find the healthiest choice. Jim is maintaining the page describing his experiments with different brands of bagels on Di-Tag and he formed a small circle of other participants contributing their experiences. His newest discovery is "Tomas's whole wheat frozen bagels". During the last couple of weeks he made a few records capturing his blood sugar before breakfast and after breakfast. Jim reviews his captured records on Di-Tag site and decides that the results are satisfactory and ready for sharing with others. He updates the page "bagels" with his newest discovery, suggesting "Tomas's whole wheat frozen bagels" as the lowest impact bagels.

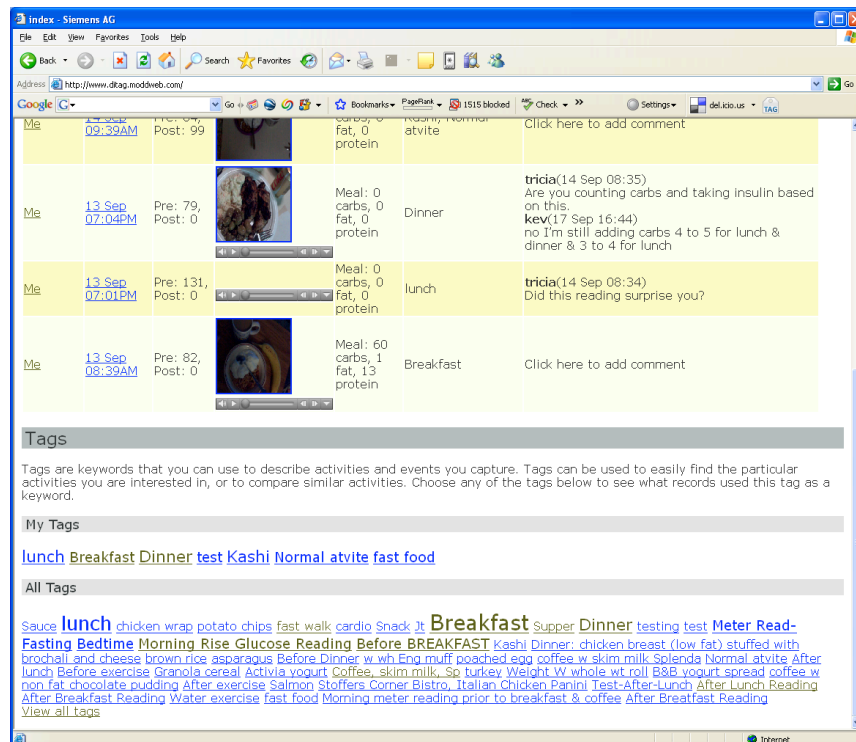


Figure 7: Di-Tag screenshot; the tag cloud.

Additional screenshots of the Di-Tag website are included in the Appendix G.

Deployment Study and Results

Participants and Procedures

In the deployment study of Di-Tag I decided to focus on the communication and learning within an existing community. Consequently, I chose one of the support groups at the same Diabetes Education Center where my other studies were conducted. This particular support group was meeting twice a month and was facilitated by the diabetes educator that worked with me during MAHI studies. The group usually included 7-8 core members who attended most of the meetings; in addition another 5-6 individuals were also present at each meeting, but attended the meetings infrequently or were new to the group. All individuals in the group were offered an opportunity to participate; 6 individuals, all core members of the group volunteered to enrol in the study. The study lasted 6 weeks; during that time the group met 3 times. All the participants took part in qualitative interviews that lasted 45-60 minutes, and were conducted prior to the study, and once it was completed.

Results

As with MAHI, the participants created a large collection of records with a fair mix of records that included blood sugar values and records that captured questions, problems or experiences using rich media, such as images and audio. Perhaps because the participants had higher level of diabetes awareness, and longer experience with diabetes, their average number of records was noticeably higher than that of MAHI users. One of the first questions of Di-Tag deployment study was whether and how individuals with no prior experience with tagging applications would engage with the tagging mechanisms, whether or not tagging will be used at all, what types of tags will be created

and whether the tags will be shared between the individuals. Below I discuss two main benefits of Di-Tag as compared to MAHI. First of all, the ability to access records of others and compare them with one's own collection of experiences helped individuals reassess their understanding of baselines for acceptable behaviors health indicators. In addition, tags required more structured annotation, which helped on both individual and community levels. Individually, it helped individuals to access their own records in a more structured way by filtering and sorting by tags. Communally, it exposed individuals to the multiplicity of interpretations, thus enriching their understanding of their own experiences.

At the same time, the design of Di-Tag as well as the design of the deployment study had a number of limitations. Most importantly, Di-Tag users felt that the application was too focused on access to and analysis of data and lacked essential community building mechanisms, such as the ability to create and maintain one's own profile and access profiles of others. This made interactions with Di-Tag impersonal and discouraged the users from a more active engagement. In addition, because most users were new to the social tagging mechanisms, the 6 weeks of the deployment study were not sufficient to overcome the initial learning curve.

Usage of Tags

After the first week of using Di-Tag, the participants created a small tagging vocabulary of over 50 tags. In some cases tags were reused between individuals, however, more commonly, participants tended to reuse their own tags, even if similar to those created by others (for example, "Morning meter reading prior to breakfast & coffee" and "Before BREAKFAST"). The main categories of tags included: types of

meals (breakfast, etc.), types of foods (green beans, coffee with splenda) and description of the nature of blood glucose readings (before breakfast, after exercise). Not surprisingly the most popular tags included the types of meals (“breakfast”, “lunch” and “dinner”), closely followed by the type of blood glucose reading (“before breakfast”, or “after dinner”).

Often, the individuals’ first tags replicated those suggestions by the researchers, or found within records of other participants. However, within days most participants started experimenting with creating their own tags, varying their format (for example switching between one-word descriptions and more elaborated ones) and content (varying the degree of specificity versus generality of the tag, for example, “breakfast with coffee and splenda” versus simply “breakfast”).

Reassessing Baselines

Both CHAP and MAHI focused on individual usage and either an individual user or a student-teacher dyad. Di-Tag, however, was designed for a community of users. One benefit this design had from the perspective of breakdowns is that it allowed users to compare their own BG readings and experiences with those of other participants. In several cases, lower average readings of others in the community caused individuals to reassess their understanding of “normal” or desired ranges.

“I saw a number of people having fairly regular readings in the 70's and 80's. It has been rare for me to have those numbers with any consistency. And I thought I was doing well with an AM reading below 130.” (S30)

In addition, viewing records of breakdowns made by other participants alerted the users to aspects of diabetes management, that they were not aware of before. For

example, noticing “before meal” and “after meal” tags attached to blood glucose readings several Di-Tag users incorporated this useful practice into their own routine.

Reflective Capture

In addition to embracing the possibility of new breakdowns through comparisons with others, Di-Tag further extended the idea of articulation by encouraging individuals to assign tags, or short descriptive key words to each newly made record by either choosing from a list of tagging vocabulary created by all Di-Tag users, or by devising their own. Incorporating these social tagging mechanisms served several purposes. On one hand, it encouraged individuals to formulate their opinions in a more concise and structured way:

“Every time I had to come up with a new tag, it made me think a bit about the record; coming up with a short but descriptive key word is not very easy...” (S3)

This observation brought to my attention the notion of *reflective capture*, or a mode of interaction with capture and access applications that blends together components of capture and access and encourages individuals to reflect on the data at the time when these data are captured.

Structured Access to Records

Qualitative interviews with the study participants indicated that tags were found useful in helping individuals structure their records, or to notice internal consistencies. For example, they saw the ability to sort data according to tags as an important asset; this allowed them to filter extensive records and focus only on those of interest. One common example of such usage was selection of a particular type of meal, for example breakfast and corresponding blood sugars. This was especially helpful to those whose record grew

substantial (over 50) and whose record web-sites consequently grew long and required extensive scrolling.

“It was actually quite useful to see all my breakfasts one after another, it really showed me how my eating habits changed over these weeks!” (S22)

Appreciating Multiple Interpretations

And finally, access to records created by others, and tags associated with these records exposed individuals to the multiplicity of possible interpretations of similar events and activities, thus enriching their understanding of diabetes. In Di-Tag deployment studies, participants created many different tags to describe relatively similar experiences. For example such tags as “morning reading”, “fasting reading”, “before breakfast reading”, all referred to the same activity – the first blood glucose reading taken upon waking; yet the three different tags used to describe it showed that different participants stressed different aspects of this activity. Later in the post-study interviews, the participants noted that seeing this diversity of descriptors made them wonder about potentially different points of view on similar activities and made their own understanding of these activities richer and more multi-faceted.

“It was interesting to see what other people paid attention to, what words they used to describe things” (S30)

Community Behind the Records

Of all my research prototypes, Di-Tag was meant to include the most sophisticated form of assistance for structured discourse: an opportunity for individuals to collaborate on writing up their experiences with different activities or different approaches to the management of diabetes. Despite my expectations, and the initial

positive feedback from the participants recruited for the Di-Tag deployment study, the collaborative writing feature remained underutilized throughout the study. The several attempts of the diabetes educator, who served as a facilitator of the online community, to engage participants in writing about the most popular types of records, for example, “breakfast” or “fasting morning reading” was met with little if any response from the participants. The qualitative interviews with the participants at the end of the study indicated that one of the possible reasons for such low engagement with the writing, and, in fact, one of the main limitations of Di-Tag, was its explicit focus on data analysis, rather than on fostering community and helping individuals to form their identity and find a way to communicate it to others. Di-Tag was designed in the general spirit of Wikipedia; its primary focus was on the data, tags and articles. As a result, the identities of individuals who contributed to the records and the tags remained somewhat hidden behind these public artifacts. However, in a diabetes management community this approach proved to be sub-optimal. Even though most participants knew each other personally—in fact most of them attended the same diabetes support group for years—the interface to the same community provided by Di-Tag felt impersonal with too much focused on data, and not enough focus on people.

“I know that I know all these people... Still, sometimes I wanted to just see how they are doing and what they’ve been up to and just to say hi or something... But to get to anybody I would have to start with tags and then go through all the records fishing out who is who. It wasn’t really easy to get to people through all of that.”

(S3)

Conclusions

In this chapter I described the last of my research prototypes designed to support reflection in diabetes management. Similar to CHAP and MAHI, Di-Tag relied on a mix of automated and user-driven capture of records describing individuals activities and blood sugar values. However, comparing to other prototypes, Di-Tag relied less on automated capture and allocated users a more proactive role in determining what to capture and how to capture it. At the same time, Di-Tag further increased individuals' engagement with the capture, by prompting them to tag the captured records and share the tags with others in the community.

Di-Tag deployment study showed that tags were beneficial on multiple levels. First of all, they inspired individuals to ponder the meaning of the records and find a concise way to classify them. In addition, filtering and sorting the records by tags provided individuals with a more structured access to their own records. And finally, they exposed individuals to the multiplicity of interpretations of diabetes-related experiences within their community.

However, the study also showed the importance of better-developed features for building a community, developing one's identity within this community, and accessing others.

PART III: DESIGNING UBICOMP APPLICATIONS FOR
REFLECTION AND LEARNING

CHAPTER 8

REFLECTION AND LEARNING IN DIABETES MANAGEMENT AND BEYOND

Introduction

In this dissertation I discuss the challenges of designing ubiquitous computing technologies that assist people in managing chronic diseases when a fundamental concern is enabling *reflection* and learning from past experiences. My conclusions, proposed in the thesis statement and discussed in further details in this chapter, stem from a series of projects that explore the potential of computing technologies to assist individuals in management of one such chronic disease, diabetes. I approached this challenge with a general goal of designing computing applications that help people adopt healthier behaviors and generally increase their sense of control over their health and disease. My studies of existing diabetes management practices showed that one of the main challenges of diabetes management lies in its demand for thoughtful and proactive engagement from the affected individuals. Due to the high variability between cases, each individual must find the combination of diet, exercise and, potentially, medication that works for them through experimentation and reflection on their own past experiences. In a way, individuals need to become “detectives” searching for clues to successful diabetes management in their past, or “scientists”, generating and testing hypotheses regarding problematic or beneficial choices. Consequently, finding ways to design computing technologies that help individuals reflect on and learn from their past experiences became the overarching goal of my PhD work.

One of the most common approaches to assisting individuals with chronic diseases in management of their health is in utilizing computing for automated capture of individuals' activities and relevant indicators of their health and allowing the individuals to access and analyze the captured data at a later time. For example, researchers introduced creative ways to use audio records of chewing sounds to discern individuals' diets (Chan *et al.*, 2006), or to use RFID tags to infer individuals' daily activities (Intille, 2003). Notably, these applications often strive to reduce individuals' participation in the capture process. However, the deployment studies of three ubiquitous computing applications that facilitate reflection in diabetes management that I designed as part of my dissertation work showed that, at least in case of chronic disease management, reliance on automated capture does not necessarily lead to reflection and learning. In contrast, engaging individuals with the capture process helps them take a proactive stance towards learning and achieve new understanding.

This argument resonates with a larger tension in the field of ubiquitous computing between the proponents of the traditional calm computing paradigm and its recent critics. The vision of calm ubiquitous computing, first introduced by Mark Weiser (1991), renders computing as proactive and intelligent in determining what data to capture without specific directions from its users. Moreover, calm computing applications are capable of selecting the moments of individuals' lives that are the most appropriate for presentation of the collected data. In this vision, the clever computing technologies provide invisible yet indispensable assistance, constantly informing and guiding the actions and choices of their users.

In recent years there have emerged several calls to re-examine the notion of calm computing that questioned both its plausibility and its long-term impact on people's creativity, problem-solving, and learning. Two notable examples of such critiques are Bell and Dourish (2007) and Rogers (2006). While there are some important differences between these works, they both advocate moving away from advancing intelligence of computing, as imagined in research labs, and concentrating on supporting intelligence of its users in the context of their “messy” and unstructured daily lives. According to these authors, the new focus of ubiquitous computing is on promoting *engagement* between computing and its users by inspiring wonder, creativity, and playful explorations, and by supporting individuals' actions in rich social, cultural and historical context.

In this dissertation I present three case studies that argue for the importance of engagement in promoting learning with ubiquitous computing in the context of diabetes management. Specifically, they show the importance of structuring reflection around situations when individuals experience *breakdowns* in their routines or understanding and of helping users transform these breakdowns into reflective moments. At the same time, these studies show that the sole focus on engagement can lead to insight that can at times be ephemeral and fleeting, rather than to a systematic increase in understanding. To achieve such systematic growth, two additional properties become of increasing importance: *continuity* in thinking that leads to systematic refinement of ideas and *articulation* of thoughts and understanding that helps to transform insights into knowledge. Combined, these three attributes can help individuals not only engage in reflection, but also sustain a productive engagement that leads to new understanding. In a way, the ideas described here present an even further departure from the calm computing

paradigm, since they advocate not only engagement but also effort, an inescapable component of successful learning.

In this chapter, I further elaborate on the three principles I discussed above, ground them in related concepts and theories from such areas as cognitive and social sciences, show the empirical evidence from the three deployment studies that served as a basis for this dissertation, and discuss how these principles manifest themselves in the larger field of ubiquitous computing. It may appear that these principles call into question the benefits of automated monitoring altogether. To address these questions I will conclude with the discussion of the advantages of automated data capture coupled with features for promoting engagement, continuity in thinking and articulation.

Understanding Engagement

The term engagement, used by Rogers in reference to individuals' experience with technology, is multifaceted and complex, and has a rich history in several domains of scholarship. Its etymology reveals a number of meanings; most of them imply a general sense of commitment (as in speaking engagement, or marital engagement). Below I discuss several domains of investigation that place particular importance on engagement.

In Media Studies engagement generally refers to individuals' dramatic involvement in a narrative. Douglas and Hargadon (2001) use it to describe a reader's ability to reflect on and critique the narrative as it is being read:

“the pleasure of immersion stems from our being completely absorbed within the ebb and flow of a familiar narrative schema... engagement lies in our ability to call upon a range of schemas... and to venture in the direction of authorial intention.” (Douglas

and Hargadon 2001)

In this domain, engagement is often connected with immersion, or the state of absorption in a narrative.

Another domain of scholarship where the concept of engagement plays an important role is education. The proponents of constructionism (Papert & Harel, 1991) place particular attention on learning through involvement in personally meaningful construction projects. Greg Kearsley & Ben Shneiderman (for example, Shneiderman, 1994) explicitly articulate the idea of engagement in their Engagement Theory of learning:

The fundamental idea underlying engagement theory is that students must be meaningfully engaged in learning activities through interaction with others and worthwhile tasks... By engaged learning, we mean that all student activities involve active cognitive processes such as creating, problem-solving, reasoning, decision-making, and evaluation. In addition, students are intrinsically motivated to learn due to the meaningful nature of the learning environment and activities. (Kearsley & Shneiderman, 1999)

The authors further define specify that engaged learning needs to:

1. Occur in group context (i.e., collaborative teams);
2. Be project-based; and
3. Have an outside (authentic) focus.

The learning I have discussed in this dissertation has much similarity with the learning described within the Engagement Theory of learning. Two of my research prototypes treated learning as a social phenomena. All three of my applications supported

learning through specific projects, or, in case of diabetes management, specific problems, and all three had an authentic focus.

Finally, the term “engagement”, or “engaging user experience” is a central theme of Yvonne Rogers’ critique of calm ubiquitous computing (Rogers, 2006). While Rogers does not provide an explicit definition of engaging user experience, her usage of the term appears to be consistent with the Engagement Theory of learning described above. The author argues that computing should focus on *proactive* people and on engaging its users more actively in what they currently do, thus helping people be “constructive, creative and, ultimately, in control of their interactions with the world—in novel and extensive ways.” Rogers discusses several examples of engaging computing, including technologies that support creative and playful exploration and experimentation, and create the sense of wonder and excitement. In one such example, the Hunting of the Snark adventure game (Rogers and Muller, 2006), children interacted with the computing application through a mix of digital and physical mechanisms to figure out the appearance and behavior of an imaginary creature, the Snark. Because there was an element of non-determinism in the behavior of the system, it created the sense of wonder and intrigue and inspired the children to find creative ways to experiment with Snark’s behaviors.

In the following sections, I will attempt to extend Rogers’ notion of engaging computing, specifically as it refers to reflection and learning in chronic disease management. I will discuss ways to design computing that not only creates engagement, but also helps individuals to learn about complex and challenging real world phenomena in a systematic way.

Supporting Learning through Engagement

Reflecting on Breakdowns

“As long as our activity glides smoothly along from one thing to another, or as long as it permits our imagination to entertain fancies at leisure there is no call for reflection. Difficulty or obstruction in the way of reaching a belief brings us, however, to a pause.”

John Dewey, “How We Think” 1933

Many schools of thought stress the importance of problems, puzzles that need resolution, hesitation, uncertainty, and other forms of *breakdowns* as triggers for and sources of learning. In the language of sensemaking, breakdowns happen when individuals experience “a fleeting sense of meaning of situations” (Weick, 2005). When confronted with an unexpected situation, individuals notice its salient properties and articulate them in language. This realization and articulation of breakdowns serves as a trigger for and beginning of reflection when individuals become open to analytical engagement with the situation. In educational literature, researchers refer to a similar notion of *teachable moments* (for example, McBride *et al.*, 2003) to indicate occasions in children’s daily lives when they are most receptive to instruction and explanation. Consistent with this view, my own observations of users’ engagement with health monitoring applications rendered breakdowns in individuals’ routines or their understanding as the most opportune moments for engaging them in reflection.

By definition, breakdown is a mental state, a reaction of a mind to a particular state of the world. Consequently, one approach to helping individuals embrace breakdowns is by using sensing capabilities of ubiquitous technologies to *reveal* various aspects of the state of the world otherwise invisible for the humans, and to give them

embodied form that can be perceived by human senses. In fact, using sensing technologies to highlight certain aspects of the world and inform individuals is central to ubicomp. One of the classic ubicomp applications, the Dangling String (Weiser, 1991), did just that by mapping the flow of network traffic to a suspended string connected to an electric motor. However, as in most ubicomp applications to this day, the Dangling String remained ignorant as to what states of the network traffic were intelligible to its users and what states led to confusion and puzzlement. As a consequence, it lacked the tools to help its users capitalize on these moments of breakdowns and turn them into opportunities for learning.

Yet another approach to using technology to create breakdowns is by helping people view familiar events, situations, and environments in an *unfamiliar way*. For example, Urban Probes (Paulos and Jenkins, 2005) go beyond mirroring aspects of the real world, helping to invoke reaction and possible breakdown. They themselves serve as sources of breakdowns, thus reversing the notion of calm computing. The actual artifact created by the researchers, the augmented trashcan, was designed to make urban dwellers pause, observe the artifact, ponder its meaning, experiment with it, and construct their own meaning of it. This interaction helped the individuals reflect on how the dynamics of urban life are reflected in trash, an unremarkable yet articulate part of the urban infrastructure. In a similar fashion, the Tableau Machine (Romero *et al.*, 2006) helped inhabitants of a house to view the dynamics of their household in new and at times unexpected ways. By introducing an element of ambiguity into the mapping between the household motion data collected with video cameras and an abstract visual display, the Tableau Machine inspired creative interpretation and led to spontaneous experimentation.

In contrast to the more straightforward monitoring applications, these disruptive technologies celebrate ambiguity of mapping between real world situations and their digital representations. In the words of the designers of the Tableau Machine, this ambiguity inspires enchantment, creating that difficulty in finding an explanation or reaching a belief described by Dewey.

There is a subtle distinction between supporting reflection during breakdowns and delivering *just-in-time* information. Steven Intille (2003) builds upon theories of behavior change to argue that there exist certain moments in individuals' lives when they are more likely to act on information, such as health messages, they are presented with through computing systems. For example, if individuals are presented with a simple message regarding heart health as they near the choice of either stairs or an escalator, they are more likely to choose stairs. This approach is more akin to the traditional calm computing paradigm, where computing guides individuals' actions by influencing their choices. In my view of reflection through breakdowns, computing technologies create or accentuate confusing situations, and help individuals examine these situations, drawing on similar experiences in their past, rather than suggest a solution.

While monitoring and sensing applications can help individuals notice and react to the states of the world, thus creating opportunities for breakdowns, similar concepts can be applied to the states of the computing system itself. Researchers argue that technological constraints and limitations that create breakdowns in user experiences with computing—so-called “seams”—are an inescapable property of any computing system (Chalmers *et al.*, 2006). Instead of attempting to create “seamless” experiences, thus blinding the users to these gaps, they advocate “beautiful seams”, converting

technological limitations into opportunities for playful engagement and learning. This approach is consistent with a somewhat different interpretation of breakdowns that originates from the writings of Martin Heidegger (Heidegger, 1962). Heidegger viewed everyday common tools as extensions of an individual, rather than entities in themselves. Such tools disappear from an individual's conscious awareness and allow their users to focus on the work to be done with the tools, rather than the tools themselves. In this view, breakdowns occur when tools fail to meet the needs of a new situation, thus rising to individuals' conscious awareness. In a similar fashion, seams in computing create moments when individuals examine their experience with technology, learn about its limitations, and often experiment to find creative ways to overcome these limitations.

Turning Breakdowns into Reflective Moments

For the purposes of my research I define breakdowns in diabetes as *moments in individuals' daily lives when their diabetes rises to their conscious thought and attention*. Examples of such breakdowns are situations when individuals need to make dietary choices (e.g., buying groceries, or ordering in a restaurant), or wonder about their health indicators (e.g., while looking at the recent blood sugar readings). The notion of breakdowns is particularly relevant for diabetes management: in the weeks and months following the diagnosis, individuals learn to “problematize” even such routine activities as grocery shopping, cooking, and attending social functions.

My design efforts in engaging reflection through breakdowns focused on two main approaches: 1) utilizing monitoring mechanisms to *reveal* certain properties of the world otherwise hidden from the individuals, and 2) providing features that allowed

individuals capture their experiences and reflection at the time of breakdowns and *articulate* their emerging understanding of the situations.

Breakdowns with CHAP

CHAP was my first attempt to help individuals learn with ubicomp applications. As a consequence, it included relatively straightforward features; its primary focus was on capturing data that can draw individuals' attention to certain aspects of their disease that required examination. The frequent (every 5 to 10 minutes) and, notably, non-invasive capture of blood glucose values, available with the GlucoWatch (<http://www.glucowatch.com>), helped individuals notice and examine daily patterns of change in their blood glucose values. Comparison of these data with records of activities, captured by the sensors and augmented by the participants in a diary, led to wonder and discovery. For example, one of the participants of CHAP studies, Mary, noticed an emerging correlation between her breakfast choices and her blood sugar values:

“You know, I am starting to notice that every time I have this new cereal, my blood sugar goes up; can it be possibly true?”

Any negative consequence of raisins, as a natural product, seemed counterintuitive to Mary; however, this suspicion required further investigation. Each subsequent day's readings increased Mary's confidence in her conclusion. Before the end of the study, she was convinced that raisins led to the rise in the blood sugar. Dieticians consulted during the study confirmed the suspicion; due to their high glycemic index, raisins, as well as grapes, lead to a quick rise in blood sugar values.

However, while CHAP contributed to creating breakdowns for its users, its ability to capitalize on such breakdowns, and encourage reflection and articulation of opinions

was limited. Most importantly, separating capture of activities, which happened throughout the day, from the analysis of these activities, which happened in the evening when all the data was aggregated and presented to the individuals, led to many missed opportunities for reflection. Sometimes, during evening interviews, the participants mentioned an unusual reading they noticed during the day and wondered about. However, by the time of the interview, their attention was mostly focused on the most recent activities that happened immediately prior to the interview. In addition, while all the reflective monologues were audio-recorded for the analysis, these records were not available to the participants of the studies. As a consequence, the insights they might have had during these interviews were often lost in the subsequent days.

Breakdowns with MAHI

To address these limitations, MAHI included a number of new features. It was designed as a mobile application available to users anytime and anywhere where they could use a mobile phone. A Bluetooth module allowed MAHI to record individuals' blood glucose readings captured with a conventional blood glucose meter, thus creating a baseline grounding for potential breakdowns and learning opportunities. In addition, MAHI allowed individuals to use voice notes and pictures to record their initial reactions to the blood glucose readings, capture breakdowns unrelated to these readings, and record their questions, concerns and ideas. Not surprisingly, more than 50% of all the conversations captured on the participants' websites started with a record of a breakdown by a participant. Moreover, the evidence of learning in these conversations was much more apparent than in those, for example, that started with a comment or an advice from the educator. In fact, many captured conversations followed a similar pattern: upon

examining the records of individuals' activities the educator would observe a certain behavior that was likely to lead to a problem, and would attempt to raise the participant's awareness of the problematic behavior. In the example below, pictures of a participant's meals alerted the educator to the lack of vegetables in the participant's diet. During the first week of the study, the educator made repeated attempts to bring this issue to the participant's attention:

BG

Picture



Discussion:

P30: Did you have any veggies with this meal? How many carb servings do you think you ate?

E: No veggies other than lettuce and tomato on the sandwich. I would estimate that this sandwich on the bagette was at least 3 carbs worth.

But it was not until a relatively serious breakdown for the student that he perceived lack of veggies as a problem and felt compelled to take steps to address it:



P30: Good heavens 216 that's no mistake unless the meter is flawed but I think I overdid the rice and I did have a bigger portion of the chili than I should have.

As a consequence, the student followed the educator's advice to increase the proportion of vegetables in his diet with an almost immediate improvement in the blood sugar:

127



E: I guess the veggies work? Interesting that the blood sugar remained so stable. I hope you like veggies/ Thank you, Tricia

P30: Yes. I will admit that doubling up on the veggies would not have been my first instinct! :)

Next time, when a similar problem occurred, the student volunteered the lack of veggies as a possible explanation without the help from the educator:



E: Did you check your blood sugar before bed? Was it indeed high? what made you think it would be high?

P30: I did not balance this meal with veggies! :(

The example above shows that access to blood sugar values coupled with records of activities could help the students notice and appreciate problematic behaviors and choices that need modification. Just as importantly, annotating the captured records prompted individuals to stop, assess the reading, think about actions that might have influenced it, and articulate their emerging understanding, or lack thereof, most commonly in a voice note. The excerpt below is an example of a typical annotation of a problematic blood sugar reading that caused the individual to wonder about his actions that could explain this reading:

Captured BG: 177

S24: (voice note following BG reading) Hi, this is Julie. I just took my blood sugar reading, 2 hours following breakfast. I am shocked; my reading was 177. That was after I ate Kashi

Strawberry Fields, but I also took my insulin 15 minutes ago, I didn't get it in before my meal. So... may be that's what happened. I am in shock.

During the interviews, the participants indicated that the first moments after viewing newly captured blood glucose readings were usually moments of reflection for them:

“Like I said, you know, with us I think, you know, you see a high number and the first thing that goes through your mind is “dude what did I eat that was wrong?”

You know? Or “how much did I eat that was wrong?” (S4)

And for many of them, having the opportunity to capture thoughts and questions right then and there was important because:

“nine times out of ten, by the time you go home, you forget what it is that you [thought or] wanted to ask.” (S9)

Many of these initial annotations made using voice notes grew into discussions with the educator, during which the students shared their emerging understanding and theories. During these times the educator provided her expert coaching and guidance, refining students’ developing model of the disease.

Breakdowns with Di-Tag

Both CHAP and MAHI focused on individual usage and either an individual user or a student-teacher dyad. Di-Tag, however, was designed for a community of users. One benefit this design had from the perspective of breakdowns is that it allowed users to compare their own BG readings and experiences with those of other participants. In

several cases, lower average readings of others in the community caused individuals to reassess their understanding of “normal” or desired ranges.

“I saw a number of people having fairly regular readings in the 70's and 80's. It has been rare for me to have those numbers with any consistency. And I thought I was doing well with an AM reading below 130.” (S30)

In addition, viewing records of breakdowns made by other participants alerted the users to aspects of diabetes management that they were not aware of before. For example, noticing “before meal” and “after meal” tags attached to blood glucose readings inspired several Di-Tag users to incorporate this useful practice into their own routines.

In addition to creating a possibility for new breakdowns through comparisons with others, Di-Tag further facilitated articulation by encouraging individuals to assign tags, or short descriptive key words, to each newly made record. Users could either choose from the tagging vocabulary created by all Di-Tag users, or create their own key words. These tags served several purposes. On one hand, they encouraged individuals to formulate their opinions in a more concise and structured way:

“Every time I had to come up with a new tag, it made me think a bit about the record; coming up with a short but descriptive key word is not very easy...” (S3)

In addition, the ability to filter records by tags provided individuals with new ways to interrogate the data:

“It was actually quite useful to see all my breakfasts one after another, it really showed me how my eating habits changed over these weeks!” (S22)

And finally, access to records created by others, and tags associated with these records, exposed individuals to the multiplicity of possible interpretations of similar

events and activities, thus enriching their understanding of diabetes. In Di-Tag deployment studies, participants created many different tags to describe relatively similar experiences. For example such tags as “morning reading”, “fasting reading”, “before breakfast reading”, all referred to the same activity—the first blood glucose reading taken upon wakening. Yet these three different tags stressed different aspects of this activity. In post-study interviews, the participants noted that seeing the diversity of descriptors made them appreciate potentially different points of view on similar activities, which enriched their own understanding of these activities.

“It was interesting to see what other people paid attention to, what words they used to describe things” (S30)

Learning Through Experimentation

“I hear and I forget; I see and I remember; I do and I understand”

Confucius 551-479 BC

The idea of most reliable knowledge gathered through experience and through active experimentation can be traced throughout centuries, from Aristotelian Metaphysics, to its first appearance in the writings of European philosophers such as Roger Bacon, to its popularization as the basis of modern science by Sir Francis Bacon (Dewey, 1921). Closer to our times, John Dewey viewed experimentation as the preferred method of learning, superior to passive observation, not only in science but also in a more commonplace critical thinking. Experimentation allows learners and thinkers to artificially create conditions necessary to observe certain phenomena; without human intervention these same conditions could take extended periods of time to develop naturally, sometimes exceeding human lifetime (Dewey, 1933).

Learning by doing or experiential learning became a popular approach in the field of learning sciences, where many argue for augmenting passive “hearing and seeing” type of learning through lectures and discussions with more active “learning by doing” through role-playing, simulations and experimentation (Green and Taber, 1978). The notion of experiential learning inspired constructionism—a theory of learning that became influential in the recent decades (Papert and Harel, 1991). Proponents of constructionism advocate learning through open-ended and playful construction of public artifacts. Agency and empowerment of learners are important concepts in constructionists’ approach; the learners themselves choose what they want to construct and have control over the construction process.

Experimentation plays an important role within the engaging computing paradigm. Rogers (2006) proposed supporting playful experimentation and learning as one of the ways to encourage individual’s proactive engagement with the world around them. She discussed several interactive learning environments that combine physical and digital in a way that allows their users to explore, experiment, improvise and create. For example, *The Hunting of the Snark* (Rogers and Muller, 2006), encouraged children to investigate an appearance and behavior of an intriguing imaginary creature, the Snark. Children observed the Snark’s behavior and appearance, its likes and dislikes, and experimented to uncover the missing aspects of the Snark’s identity by walking with it, feeding it and flying with it.

The example of *The Hunting of the Snark* showed that a certain level of ambiguity in a system’s behavior and engaging interaction mechanisms creates wonder and encourages spontaneous experimentation. However, when individuals’ goal is to

enrich their understanding of complex real world phenomena that develop over extended period of time, a structured and systematic approach to experimentation becomes increasingly important. In fact, John Dewey considered continuity in thinking and individuals' ability to link together thoughts and ideas in an orderly fashion as necessary attributes of reflective thinking. He distinguished this kind of thinking from other kinds, "where ideas flow without direct purpose as a result of one's fancy," more like daydreaming or stream of consciousness:

"Reflection involves not simply a sequence of ideas but con-sequence – a consecutive ordering in such a way that each determines the next as its proper outcome, while each outcome in turn leans back on or refers to its predecessors." (Dewey, 1933)

The notion of con-sequence of thinking and experimentation resonates with the criticisms of the experiential learning programs. For example, Green and Taber (Green and Taber, 1978) argue that in practice experiential learning tends to be non-integrative or non-programmatic:

"Throughout the course, the students are presented with a collage of exercises which they have difficulty tying together or relating to reading assignments. All of these problems serve to weaken the reflective observation phase of learning, thereby diminishing students' ability to develop abstract concepts, to relate their course experiences to other concepts, and to generalize to real life situations."
Green and Taber, 1978)

I argue that while it is important to engage individuals in playful experimentation, the learning obtained through such experimentation might be fragmented and ephemeral.

Computing for reflection needs to help individuals preserve continuity in their thinking and experimentation that could enable more structured and coherent learning.

Supporting Systematic Learning

CHAP: The Impact of Immediate Feedback

In my studies of diabetes management practices, I observed that experimentation plays an important role in developing and refining individuals' understanding of their disease and formation of approaches to its management. For example, in CHAP deployment studies, the availability of the immediate feedback produced with the GlucoWatch inspired both participants to experiment with different foods and monitor these foods' impact on their blood sugar levels. For example, Paul, for whom the restriction on fruit juices was one of the more inconvenient adjustments to his diet, was fascinated by his new ability to see not only the ultimate impact of the juice, measured at the standard 2 hour after meal interval, but to monitor the actual patterns of change as they developed in real time.

At the same time, this first deployment study demonstrated several limitations of CHAP to promote experimentation in a systematic and structured way. First of all, even though the high frequency of monitoring provided Paul with a window into the inner workings of his disease and allowed him to observe changes in the blood sugar values in almost real time, he deemed such high sampling rate appropriate only when he actually wanted to experiment. At other times, he felt that such high reading density was a waste of computing resources and, more, importantly, an unnecessary burden to him. High sampling rates required more frequent replacement of costly sensors and batteries. In addition, while sampling blood glucose with the GlucoWatch was non-invasive, it was

not entirely painless: each reading felt like a light sting to an individual's wrist, and constant frequent sampling at times led to skin irritation. Moreover, such high frequency of readings led to the continuous growth in the amount of data (the GlucoWatch produced over 2000 readings during the 2 weeks of the study) needed to be processed and analyzed. Similarly, the static configuration of the motion detection sensors in the participants' house was perceived as too rigid to allow for experimentation. All these observations highlighted the need for the users of the technology to be able to modify configurations of the sensing components of the application to accommodate their experiments.

While both participants conducted numerous experiments, transcripts of daily interviews revealed a certain degree of fragmentation in their learning. For example, Mary's first hypothesis was regarding the particular brand of morning cereal that led to increase in her blood glucose values. But while the application allowed her to record her breakfasts, it lacked the flexibility to record different configurations and variations that she tried. As a result, when reviewing the data captured during the previous days, she could not recall which configuration of milk and cereal (i.e., skim milk or whole milk, raisin bran or cheerios) she tried during those days. There was also little opportunity to plan ahead and set up new parameters for future experiments. This observation revealed the need for a better support for structuring and planning the experiments, and for mechanisms that would help to maintain coherence in learning.

MAHI: Supporting Coherence in Learning

MAHI was designed to address some of these limitations. User control of configuration of blood glucose monitoring became non-essential in MAHI, since it relied on user-initiated blood glucose readings. However, MAHI provided two main features

that proved important in supporting systematic learning: visual coupling of data with annotations and discussions about that data, and a persistent history of these contextualized discussions captured throughout the study.

One of the main advantages of MAHI over other record-keeping devices available to the students was its ability to not only capture both blood glucose values and everyday activities and present them side-by-side, but also to engage its users in ongoing discussion over these records. The visual proximity of records and discussions assisted students in planning and structuring experiments with different types of meals or exercise routines and viewing results of their experiments. The persistent history of these contextualized discussions allowed for a more systematic approach to experimentation, helping individuals gradually refine their understanding and eliminate sub-optimal choices. In the excerpt below, the participant gradually varied different types of the bedtime snack, until he found the solution that produced the optimal outcome (lowest blood sugar value on the following morning):

S23: I am trying a green apple b4 [before] bedtime.

S23 (next morning): Blood count this morning was 107, so perhaps green apple is working or perhaps it was 5 hours of sleep. So we will keep trying the apples.

A few days later:

s23: had 1/2 grapefruit at bedtime

s23 (following morning): grapefruit isn't working as well, back to apple

This systematic approach to experimentation helped the participants thoroughly cover the range of possibilities, which was especially important for activities that had specific importance or attraction:

“You know, I was trying to stick with the orange juice in different variation. You know, trying like a low sugared orange juice or less orange juice... because I didn’t want to give it up. You know, I’m stubborn. I didn’t want to give it up. And I ultimately did, but yeah, I wouldn’t do it without a fight, you know” (S8)

More generally, the ability to review the entire history of individuals’ records coupled with annotations and discussions had a number of important benefits. In addition to enabling more systematic experimentation, it helped individuals link discrete discoveries into *coherent learning threads* that developed over days or weeks. An example bellow illustrates how a particular learning thread (balancing breakfast protein) can develop over the course of several days. In this example a combination of captured records allowed the educator to formulate a recommendation, which was acknowledged by the student and later incorporated into his practice:

P23:



E: Breakfast I would recommend a more substantial protein and not so much carb with that blood glucose level. ie pb or egg or cheese

S23: OK protein in the morning.

A few days later:

P23:



S23: Dear Sugar Queen, Our fare this AM is egg beaters with cheddar cheese and three color bell peppers with a side of peanut butter on one english with a chaser of 12 oz V8. OK on the 2 hour bg when i can remember. Do you think we got the proteins in the mix this morning, LOL?

These threads helped the participants experience learning as a gradual process with continuity and coherence:

“So, it was kind of like education where you’re getting to the next level. So we were starting with the basic, you know, what is this and then more of well, how about you added this or this and then finally, we’re at the point where we’re kind of dialoging about the um, the orange juice and the... you know, good points and bad points about taking it.” (S9)

These histories had an additional benefit of allowing students to observe the progress in both their blood glucose readings and their understanding of their disease, thus inspiring and contributing to *metacognition*. The excerpt below illustrates how a simple question from the educator triggered a thoughtful and reflective response from a student:

Captured BG: 126 [down from 140s at the beginning of the study]

E: How do you feel about this number?

S3: Interesting question. I feel good about it in that I think that it shows that I am beginning to get control of my BG numbers. I can see the relationship between the choices that I make each day and the test results that I am seeing. The numbers are coming down, but I would like to see them lower still. I will continue my exercise regimen, and will continue to be more selective in what and how much I eat. I'm hoping that as I continue to lose weight, the numbers will continue to drop. In looking over the numbers on this page, I see that only 2 weeks ago my morning numbers were often in the 140's, and now they are in the 120's - 130's. That makes me feel good.

Because the participants could see changes in their own thinking about diabetes, their approach to solving problems, and their attitude to self-care, they were able to realize and appreciate their own mastery, thus contributing to their growing self-confidence. The excerpt below shows a student's transition from relying on educator's judgment to more confidently sharing his own conclusions. This transformation, evident in qualitative data, is consistent with the quantitative measure of transformation of individuals' locus of control and further supports this finding.

First week of the study:

s3: my morning bg levels often seem higher on the weekends. i usually sleep a little longer on sat. & sun. (~ 8 1/2 or 9 hours instead of the usual 8), and i was wondering if this could be the cause of the higher numbers. **is this possible?**

e: absolutely, it is a longer time span without eating and the liver puts out more sugar. also if you have wine etc it blocks

the use of sugar and can cause a rebounding in the blood sugar level.

Last week of the study:

s3: i had a yogurt before bed last night, but **i realized** after i ate it that it was a "regular" yogurt instead of a "lite" one. too many carbs. and since i had the chocolate earlier in the evening, i probably shouldn't have had anything at bed time. there's so much to learn when dealing with this.
e: sounds like a really good learning experience.

Di-Tag: A Note on Agency

The design of Di-Tag replicated many MAHI features, at least in regards to supporting structured experimentation and continuity in learning. However, one episode from the Di-Tag deployment study further confirmed the importance of respecting users' agency and providing individuals with a flexible control over an application's sensing configuration. During MAHI studies, users frequently expressed their desire to have a reminder to capture blood glucose reading two hours after a meal. After this feature was added to the application, it led to a wave of complaints from the participants and was quickly removed. Qualitative interview revealed that the set time for reminders was too rigid to accommodate users' experimentation. They wished for an opportunity to plan their experiments and set up reminders at times they felt were appropriate for each particular situation: for example, every 10 minutes during a half-hour interval in case of hypoglycemia (dangerously low blood glucose level) or every hour for up to 6 hours in case of meals including slow-acting carbohydrates.

This observation regarding the importance of user agency for experimentation and learning has a number of consequences for the design of computing technologies for reflection. Many capture applications strive to hide the configuration of sensing features from the users. In these applications, the designers establish what is to be monitored, and the density of monitoring based on their view of users' needs and, often, on technical constraints. And it is just as common for the users to be largely ignorant of the sensing capabilities of the system. This approach is not surprising and is grounded in the designers' desire to hide the complexity of computing applications from technologically un-savvy users. However, to allow users take full advantage of potential learning with ubicomp applications, and, particularly, to learn through experimentation, the data that the application captures need to correspond to the questions users may have about that data at that particular moment. Consequently, they need to support users' ability to modify properties of the system, for example configuration and density of monitoring, to match their questions.

Researchers in ubiquitous computing have found a number of relatively straightforward solutions to this challenge. The two examples I discuss here, the Experience Buffer (Hayes *et al.*, 2005) and the augmented timeline feature of the Designer's Outpost (Klemmer *et al.*, 2002) utilized users' input not in configuring monitoring—both of these applications capture highest density data possible—but in allowing users to *explicitly denote* portions of recording worthy of their attention. An informal user study of the augmented timeline in Designer's Outpost found that the high density of capture resulted in overload and confusion. However, the bookmark and synopsis features that allowed users to specifically mark design steps as milestones, and

present a history enriched with these milestones, was found to be of great value to users. In a similar fashion, the Experience Buffer utilized a continuous recording without attempting to filter or limit the capture based on application's perception of users' preferences; instead, it allowed users to explicitly mark segments of the captured recording worthy of archiving, deleting everything else. Both of these techniques helped users to take active part in the capture process.

A more complex solution, but also one that will afford greater user agency would require the system to espouse a greater level of *users proficiency* with *and control* over its features. This approach does not suggest that ubicomp systems should be designed only for “power” users. On the contrary, I propose that “power” access be made available to regular users. Essentially, system designers would need to find a way to increase the transparency of the system without unduly increasing the complexity of the system's interface, and provide its users with an ability to temporarily change parameters of monitoring at the time of experimentation.

From Insights to Knowledge

“The change from maximally compact inner speech to maximally detailed written speech requires what might be called deliberate semantics – deliberate structuring of the web of meaning.”

Lev Vygotsky, Thought and Language, 1986

There exist many views of learning and theories explaining learning and development of knowledge. Despite their many differences, there is a general agreement that learning involves development of mental structures that incorporate new information and integrate it with what was learned in the past. Many researchers in learning sciences

argue that articulation of ideas and opinions, particularly in a written form, facilitates this process, thus serving as a powerful catalyst to learning.

Much has been written about the impact of composition on constructing new knowledge. Lev Vygotsky, A.R. Luria, and Jerome Bruner, for example, all pointed out that higher cognitive functions, such as analysis and synthesis, seem to develop most fully with the support system of verbal language (quoted from Emig, 1977). Moreover, researchers argue that written composition in particular, as opposed to other forms of composition, such as painting or dance, and other forms of language, such as reading or talking, can empower students to reflect on what they know and integrate existing knowledge with new knowledge (Emig, 1977). Writing tends to be more deliberate, slower, and, most importantly, allows the writer to revisit his or her thoughts and, in the process, gradually refine his or her understanding. At the same time, one might argue that captured verbal dictation, while perhaps inferior to writing, can play a similarly important role. Not surprisingly dictation already plays an important role in many clinical fields, for example radiological analysis or pathology.

Of the three principles I advocate in this dissertation, articulation of ideas and opinions and negotiation of meanings through verbal or written discourse appear to be the least explored as pertains to the ubiquitous computing and capture and access applications. For example, the authors of both Urban Probes and the Tableau Machine discuss the potential of their applications to inspire storytelling and discussion. However, neither application provides features specifically designed to capture such discussions, leaving it up to the users to come up with creative solutions to compensate for this limitation. For example, users of Tableau Machine actively used printing features,

preserving a persistent record of the system's visual states for future reflection and for sharing with others. These printouts were then pinned to household refrigerators or other places of shared activity where they could be available to others.

There are, however, inspiring examples of more traditional computing that explore new mechanisms for articulation and social construction of meaning. One increasingly popular mechanism for a community of individuals to converge on a shared opinion is social tagging. While there have been various social tagging mechanisms developed over time, the main premise of the approach is in allowing individuals to assign free-form key words, or tags, to items of interest and in storing thus annotated items in a shared repository. Examples of such items could be digital documents, such as files, images, or URLs. When multiple people use identical tags for items, aggregation of such tags leads to emergence of a user-created categorization scheme, known as a "folksonomy" (Vanderwal, 2006). These folksonomies reflect consensus of opinions reached by a community or a diversity of opinions espoused by the community in regards to a particular phenomena. However, the knowledge reached through social tagging remains ephemeral, until it is captured in a more stable form, for example in writing.

The power of written discourse in engendering new knowledge and ideas is encapsulated in the success of Wikipedia (Bryant *et al.*, 2005), an online encyclopedia built on wiki technology that allows willing volunteers to engage in collaborative writing of articles. The democratic spirit of Wikipedia is in close accord with the social tagging approach and with the general notion of individual empowerment I advocate. From its inception, Wikipedia allowed individuals to engage in creating and editing articles without registering or otherwise applying for editing privileges. While there are more

recent restrictions to the editing policies, the general spirit of collaborative writing remains intact.

Enriching Discourse

CHAP: Discourse as Part of Study Design

In CHAP, opportunities to formulate opinions and engage in discussions were included as part of the study design, rather than a feature of the application itself. During the deployment study, a member of the research team (most commonly myself) conducted daily interviews with each participant, engaging them in a discussion about the data captured during that day. Notably, even though many individuals' observations of certain intriguing dependencies between their activities and blood sugar values were made throughout individuals' days, both participants felt that these daily meetings were an important part of the study:

"It's been very useful to talk through all these readings with you; I think it really helped me to get a grasp on what's going on here." (S2)

The quote above is particularly intriguing as it cannot be explained by the helpful feedback or guidance provided by the interviewer. Since the meeting was meant to engage the participants in the reflective monologue, the interviewer limited her part to simple encouragements to continue. The very act of verbalizing their thoughts seems to have contributed to individuals' analysis and understanding of the data.

MAHI: Contextualizing Discussions with Data

Earlier in this chapter, I discussed the benefits and the perceived value of the ability to annotate the captured data provided by MAHI. One of the main advantages of

these annotations was their ability to inspire individuals to critically think about the event they captured, contemplate its meaning, and record their thoughts in voice notes, thus making them available for reflection in the future. I argued that these annotations were the first step in inspiring reflection; aggregated histories of the annotations combined with other records contributed to the coherence in experimentation and led to the more systematic learning.

The most critical feature that contributed to individuals' growing self-confidence and mastery of their diabetes management practices were the contextualized discussions that visually coupled blood glucose readings, records of activities, annotations and discussions. Most importantly, these discussions helped both the educator and the students formulate their thoughts in a way that was mutually accessible, thus increasing visibility of their approaches to thinking and reasoning about diabetes-related problems. This increased visibility was a critical factor in enabling cognitive apprenticeship as a learning style in MAHI deployment studies. A more detailed discussion on cognitive apprenticeship is included in chapter 3. Below I reiterate some of its main attributes and show specifically how contextualized discussions contributed to the transparency in thinking, and helped students who used MAHI refine their understanding of diabetes.

Much of learning with MAHI evolved around solving specific diabetes-related problems identified by either the students or the educator. Most commonly, these problems stemmed from undesirably high blood glucose readings. Once the problem was identified, and after some initial negotiation regarding its nature, the educator examined available students' records looking for potential causes and formulated a series of questions for the student. These questions helped the educator fill in the gaps in the

records, and, most importantly, they *demonstrated* to the students how to engage in reflective analysis of their past experiences, what to look for in the data, how to formulate hypotheses, and how to look for empirical evidence for their emerging theories. In the example below, the educator responded to the student's indication of a problem with a series of questions that examined potential causes of the problem:

E: That is a very common question and also frustrating. What time was dinner? Did you have a chance to consume a snack? The long time span between dinner and AM often causes the increased number. Remember that after about 4 hours the liver needs fuel. A snack of 1 cup of milk or 1/2c fiber cereal + 1/2 c lowfat milk will help bring this number down. It will delay sugar production.

In turn, the students used these discussions to formulate their theories regarding dependencies and influencing factors in diabetes, and share their emerging understanding with the educator. During this time, the educator observed participants' experimentation with different activities, and *coached* them through developing their own operational model of diabetes by providing feedback, at times correcting and guiding students' theories.

S3: I noticed this morning when I took by blood pressure pills that I forgot to take them yesterday (Sunday). I also noticed that my bg levels were a bit higher on Sunday and again this morning. Could this be a case of cause and effect?

E: Yes it could have caused your body to feel a bit more stressed and produce more stress hormones leading to an increase in the bg.

Sometimes, it was simply a matter of reassuring participants frustrated with the lack of immediate results and the complexity of their undertaking:

S3: It appears that there isn't much that doesn't affect bg levels! I suppose that worrying about bg levels will cause the levels to rise, which could cause one to worry even more, which

E: You are correct. That is why we speak of averages and ranges. Not absolutes. you are definitely moving in the right direction. Remember 90% is an A in diabetes management. Meaning 90% adherence 10 % fun

As a result, the students perceived the ability to converse with the educator, formulate hypotheses, and brainstorm on the possible solutions to the problems as one of the main benefits of the application.

“I would look at my records and write what I think was happening, and she would look at it and say, well, actually... or yes, you are right! These troubleshooting sessions, the ability to go back and forth looking at problems was the most helpful part of the study.” (s24)

As I mentioned above, the persistent history of these discussions helped the students to appreciate the gradual improvement in their understanding thus contributing to their adoption of the internal locus of control.

The observations above demonstrate the importance of the discussions in helping individuals reflect on their records and refine their diabetes management skills. However, they also lead to a question of whether MAHI could have had the same effect without the complexity of custom hardware and mobile application for automated data capture. Could

a simpler message board allow for the same exchange and experience? Interviews with study participants indicated that sharing access to data was essential for both the educator and the participants. Often, records of blood sugar values and activities captured by the students helped the educator initiate conversations, which was especially important at the beginning of the study. In addition, these records essentially became a part of the conversation, allowing the educator to monitor participants' actions and providing continuous feedback. But most importantly, the data allowed the educator to shape the questions and the coaching in way meaningful to the participant:

“Otherwise, I would just have to ask the same questions of everybody and it is very hard to engage people with generics.” (Educator)

As a consequence, I argue that sophisticated sensing techniques that target different indicators or health and various activities can be of great importance. However, these techniques need to be combined with mechanisms that engage individuals in the monitoring in addition to automating it.

Di-Tag: Fostering A Community

Di-Tag was meant to include the most sophisticated form of assistance for structured discourse—an opportunity for individuals to collaborate on writing up their experiences with different activities or different approaches to the management of diabetes. Despite my expectations, and the initial positive feedback from the participants recruited for the Di-Tag deployment study, the collaborative writing feature remained underutilized throughout the study. The several attempts of the diabetes educator, who served as a facilitator of the online community, to engage participants in writing about the most popular types of records, for example, “breakfast” or “fasting morning reading”

was met with little if any response from the participants. The qualitative interviews with the participants at the end of the study indicated that one of the possible reasons for such low engagement with the writing, and, in fact, one of the main limitations of Di-Tag, was its explicit focus on data analysis, rather than on fostering community and helping individuals to form their identity and communicate it to others. Di-Tag was designed in the general spirit of Wikipedia; its primary focus was on the data, the tags and the articles. As a result, the identities of individuals who contributed to the records and the tags remained somewhat hidden behind these public artifacts. However, in a diabetes management community this approach proved to be sub-optimal. Even though most participants knew each other personally—in fact most of them attended the same diabetes support group for years—the interface to the same community provided by Di-Tag felt impersonal, with too much focused on data, and not enough focus on people.

“I know that I know all these people... Still, sometimes I wanted to just see how they are doing and what they’ve been up to and just to say hi or something... But to get to anybody I would have to start with tags and then go through all the records fishing out who is who. It wasn’t really easy to get to people through all of that.”

(S3)

Summary

In this dissertation I propose that ubiquitous computing technologies can serve as a powerful catalyst in helping individuals reflect on and learn from their past experiences. The significant advances in sensor and capture techniques can help individuals record their experiences with unprecedented richness and density. Research shows that reviewing rich records of past activities can help individuals refresh their memories of

events and situations, a first necessary step in reflection (Sellen *et al.*, 2007). My own studies showed that the ability to capture records of activities and review them at a later time helped individuals to critically examine their choices:

““Somehow every time I looked at the images of my meals I saw something different than what I saw when I was cooking them. I always thought I was making great choices and then I would look at the picture and think – wait a second...”
(S30).

However, my experiences designing and deploying three ubiquitous computing applications that helped individuals reflect on their diabetes experiences demonstrated that higher levels of automation of data capture do not necessarily lead to learning. In contrast, the more engaged individuals were in collecting the data, the more they benefited from it and the more they learned from their experiences. This observation is consistent with the recent criticisms of the traditional calm computing paradigm that argue for transitioning from the calm computing to engaging user experiences. In this dissertation I presented three case-studies that provide further support for the benefits of engaging computing in the context of reflection in diabetes management. At the same time, these studies show that the sole focus on engagement can lead to fragmentation in learning. To support systematic increase in individuals’ understanding, computing for reflection needs to help individuals maintain continuity in their thinking and support more systematic approach to experimentation. In addition, it needs to help its users formulate and articulate their emerging theories, and engage in the social discourse regarding their growing understanding, thus helping them to transform initial insights into knowledge.

CHAPTER 9

OPPORTUNITIES FOR FUTURE RESEARCH

As is typical for any research, my investigations of the role of computing in individuals' diabetes management practices generated more research questions than could be answered in the scope of my PhD work. In this section I discuss the opportunities for future research along two general directions. On one hand, I will illustrate how the conclusions proposed in this document could be used to structure research activities in ubicomp for reflection. On another hand, I will return to some themes beyond reflection that emerged from my initial studies of diabetes management practices and discuss what opportunities for research they present.

Supporting Reflection with Ubicomp

In Chapter 3, Notes on Methodology, and throughout this document I have attempted to demonstrate my alignment with the Design-Based Research methodology, in particular its generative approach to theories and deployment studies. As a result, the conclusions and design principles proposed here are a result of my investigations, not their starting point; the design explorations and deployment studies I described here contributed to the principles and informed them, rather than served as a testing ground for them. Consequently, more research is needed now to support and validate these principles and, potentially, formulate a theory of reflection with ubicomp, which could satisfy the following criteria described by Tweney (Tweney, 1989): it makes predictions, is potentially disconfirmable, and has interesting consequences. This transition, from descriptive and interpretive frameworks to theories is not that common for HCI and HCC; in fact there are few, if any, attempts to validate or disconfirm any of the

established frameworks in these areas, for example Distributed Cognition or Situated Action. However, I believe that validating the principles through additional design explorations and deployment studies can lend them credibility and contribute to their further refinement. In the following three sections I will discuss how the principles I proposed can guide future research in ubicomp for reflection. I will not attempt to present an exhaustive and complete landscape of future research; instead I will highlight some opportunities I find particularly interesting, challenging or promising.

Engaging in Reflection

In accord to other researchers discussing engaging computing, I propose that breakdowns in individuals' understanding of particular situations that arise in their everyday lives present opportune moments to engage individuals in reflection, exploration and experimentation to resolve these problematic situations.

I discussed two main approaches to creating breakdowns, through capture of data that reveal properties of the real world otherwise invisible to the human senses and through defamiliarization. Both of these approaches present similar questions for the designers of the technologies. For example, there are different roles that computing can play in identifying breakdowns. On one hand, computing applications can be relatively passive, giving voice (or other embodied form) to the invisible phenomena in the real world, and allowing the data to “speak for itself”. On the other hand, they can reinforce salient or unusual properties of the data thus provoking or reinforcing breakdowns. For example, in MAHI studies, the educator, who essentially was a part of the socio-technical system, often pointed individuals to suboptimal dietary choices in their records that did not cause breakdowns, thus creating additional opportunities for learning. In addition,

questions remain regarding ways computing systems can increase their awareness of users' breakdowns without becoming too intrusive. On one hand, the advances in computer vision can help to automatically recognize moments of puzzlement, based on facial expressions. However, errors in recognition unavoidable in this approach can lead to user frustration and annoyance. Alternatively, the system can help users express their reactions to the data in a way that does not interfere with their ongoing activities.

Promoting Systematic Experimentation and Learning

In Chapter 8 I described several ways to promote systematic approach to experimentation and learning. One of the themes that was perhaps the least explored in my studies was the need for users to have a higher level of agency or control over application configurations, behaviors and outcomes. While I chose to focus my efforts elsewhere, this particular topic I believe has a great potential for future investigations. The need for transparency of computing systems has long been adopted as one of the guiding principles of HCI (Norman and Draper, 1986). However, the majority of ubicomp applications essentially hide their internal capabilities from users and for good reason. Finding the right way to increase the transparency of an inherently complex technology is a serious undertaking. Recently, similar challenges have been explored in the domain of home-networking, another family of applications that relies on users' understanding of system's features and functions (Grinter *et al.*, 2005). Just like home networking applications, ubiquitous computing technologies need to help their users gain appreciation and understanding of their capabilities without overwhelming users with complexity.

The next challenge lies in providing users with the right level of control over system configuration. Explorations in privacy of computing applications show that users rarely change default configurations of applications, even if they have good reasons to do so. One example of a potential direction can be found in mobile technologies: instead of overwhelming users with the need to change each setting individually, many phones now allow their users to choose profiles, pre-defined collections of settings intended for different purposes. Similarly, monitoring applications can offer different preconfigured profiles to allow for different types of experiments. The downside of the profiles is that they can be too rigid to account for the necessary variety of experiences.

Reflection and learning through experimentation often emerge spontaneously when individuals engage with a new and unfamiliar technology. For example, in the studies of Tableau Machine, users often experimented with different behaviors to see their impact on systems' state (turning all the lights in the room off simultaneously to see how it would change the display). There is an opportunity for ubiquitous computing technologies to capitalize on this initial playfulness and help recreate a similar spirit of adventure when learning about real world phenomena.

Supporting Articulation

An ability to annotate captured data at the time of capture can help users formulate and articulate their ideas and opinions, thus accomplishing a necessary step in formation of knowledge. MAHI users found annotations to be useful and natural, mostly due to the social context in which they were created – after all, recording one's thoughts in order to share them with others is a rather straightforward activity. On the other hand, annotations created in a social vacuum, and for one's own use, may seem unnatural and

awkward. The challenge for the ubicomp technologies then is to find ways to inspire articulation of thoughts in those situations where social context may not be readily available.

One of the more successful design decisions in MAHI was to allow for a choice of media for capture of opinions. We already discussed the benefits of this flexibility in regards to users' agency. The distributed nature of ubiquitous computing may limit the desired flexibility, rendering some modes (for example typing using a keyboard) unavailable. The challenge then is to find a way to allow for flexibility of media choices while preserving mobility of user experiences.

And finally, negotiation of meaning and creation of new knowledge through captured discourse with the help of computing applications remains a considerable challenge. Many researchers, including the creators of Wikipedia, find its wide success surprising and intriguing. Finding a media that would provide similar affordances in the world of ubiquitous computing would require focused investigations of the research community.

Socio-Technical Research in the context of Chronic Disease Management

My initial investigations of tensions and challenges typical for diabetes management helped me to identify a number of themes that guided much of my subsequent research work. One of these themes, the need for reflective analysis of past activities and experiences became the main topic of my dissertation. There are, however, at least two other areas of research that remained outside of my immediate focus, the importance of motivation and individuals' willingness to engage in diabetes management,

and their preference for flexible negotiation of balance between desired lifestyle and the desired state of health. I discuss these areas below.

Motivation to Engage in Self-Care

The main focus of the three applications discussed in this document was to help individuals with diabetes who recognize the need to manage their health, embrace this need, but may not know what they need to do or how to do it. These individuals, like many participants of my studies, are open to assistance and are eager to receive new information. The selection of deployment sites for two of my applications, MAHI and Di-Tag further contributed to limiting the target audience of these applications: individuals who attend diabetes-education classes and diabetes support groups tend to be self-motivated. However, as many physicians I consulted in the course of my studies told me, one of the main challenges of controlling diabetes as a worldwide epidemic is individuals' tendency to ignore it, and to refuse to take any steps towards managing their disease. This tendency towards denial is not surprising: changing one's established ways and one's preferences and likes takes discipline and sacrifice. Constant counting of carbohydrates and nutrient proportions can drain all pleasure out of food consumption, one of the most joyful and celebrated parts of human existence (Grimes, 2008). The following quote from Chapter 3 illustrates this point:

“My doctor tells me: boy, you are a trooper... you need to manage it and you need to not feel deprived. Because once you feel deprived you can sit in the corner and cry. And you can't allow that, because it is self-defeating.”

While in this document I advocate breakdowns as opportunities for learning, constant breakdowns in established and, especially, pleasurable routines may lead individuals to abandon attempts to manage their health altogether. One tempting solution is to develop technologies that completely remove these breakdowns: for example, new continuous glucose monitoring devices combined with insulin pumps can, in theory, function as external pancreas, taking care of all insulin deficiency and allowing individuals maintain their lifestyles. However, many diabetes educators feel that this solution may have some short-term gains but long-term harm: ultimately, the need for responsible management of health is inescapable. Consequently, the computing technologies need to strike a difficult balance between helping individuals to learn, while at the same time helping them maintain their quality of life.

From the somewhat broader perspective, much of the motivation or lack of motivation to engage in diabetes management stems from individuals' refusal to accept their new identity of someone with a chronic disease. Research shows that this identity management concerns can present significant barriers to responsible attitudes towards health. Viewing self as an empowered individual who has a choice and can act upon her choices can positively impact individuals' health and health management practices (Langer and Rodin, 1976).

Identity management is a complex issue. However, there are examples of computing technologies that helped individuals with chronic diseases adopt a positive image of themselves relying on positive role-models. For example, Debra Lieberman describes several "Health Hero" games for children with such chronic diseases as asthma or diabetes and argues that identifying with strong, attractive animal characters of these

games helped children and their disease-free friends to adopt a more positive image of the disease (Lieberman, 1997).

An important part of individuals' identity, cultural and social affiliation can play a significant role in determining whether and how individuals engage with such issues as health management, eating habits or physical activity. Consequently, another way to promote healthy lifestyle choices is by focusing on communities, rather than individuals as a unit of analysis. Di-Tag was my first effort to approach diabetes management from the perspectives of a community; more can be done to take advantage of or to mitigate social and cultural influences on health choices.

In one of my previous research initiatives, I, in a team of my colleagues from Siemens Corporate Research, explored the possibilities of computing technologies to assist with motivation in the context of health management. The prototype application we designed and built, Fish'N'Steps (Lin *et al.*, 2007) used persuasive computing techniques and social influences to encourage individuals with sedentary lifestyles to walk more. The application utilized pedometers, small devices that capture step counts of their wearers, to monitor individuals' activity levels and mapped these levels to the growth and development of an animated characters, a fish in a fish tank. Higher numbers of steps led to a more developed and happier fish, whereas lower numbers led to a smaller, and less interesting character. In our deployment study we found that Fish'N'Steps created a certain level of attachment between individuals and their characters and helped individuals to increase their step counts.

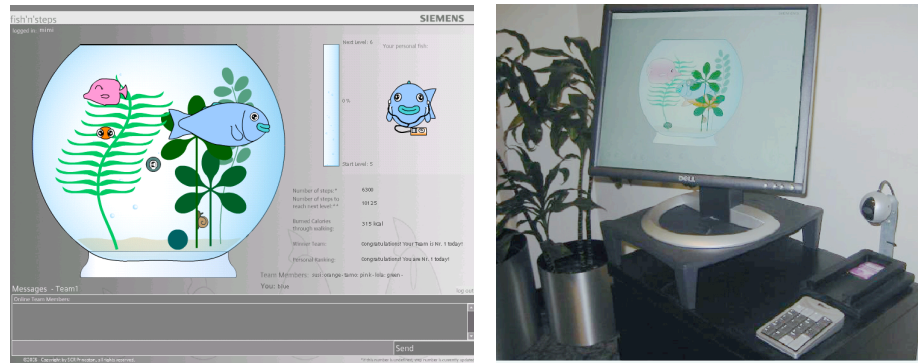


Fig. 8: Fish'n'Steps. One participant's display after approximately two weeks into the trial in the Fish'n'Steps team-condition, also the public kiosk and pedometer platform, which rotated through each of the team fish-tanks. The components of the personal display include: 1) Fish Tank - The fish tank contains the virtual pets belonging to the participant and his/her team members, 2) Virtual Pet – The participant's own fish in a frontal view on the right side next to the fish tank, 3) Calculations and feedback - improvement, burned calories, progress bar, personal and team ranking, etc., 4) Chat window for communicating with team members.

The Need to Negotiate a Balance

In the previous section, I have already alluded to individuals' desired to maintain a certain balance between their desired state of health and their quite understandable desire to maintain their regular lifestyle. Like many chronic diseases, diabetes management is not about a complete rejection of any potentially harmful activities, or adoption of a risk-free lifestyle. Instead, it's about complex and intricate system of tradeoffs and compromises that allow individuals to enjoy their lives while preserving their health. Even diabetes educators that I consulted in the course of my studies tend to say: "Diabetes management is 90% discipline and 10% fun", encouraging their student to embrace joys in life, including those associated with foods. Much of the diabetes

education focuses not only on what to avoid but also on how to compensate for the unavoidable. However, maintaining this balance can be an overwhelming task, with the scale not surprisingly often tilting in one direction or the other: at times individuals overestimate how strictly they follow their own resolutions, at other times they unnecessarily overcompensate.

In a way, this situation can be compared to managing one's personal finances, which present a similar need to balance everyday needs, wants and desires with the available capital and long-term goals. In recognition of the complexity of this task, there exist a variety of decision-support tools for personal finance; a few examples include MicroSoft Money or web-based tool Mint. These tools allow individuals to plan their budgets, and balance their earnings and spending in the context of their long-term financial goals. There is a potential to explore similar approaches in the area of diabetes management, or management of other chronic diseases. Such tools could help individuals establish long-term goals, develop "budgets", and maintain a balance between earnings, through activities that contribute to health capital and spendings, or activities that reduce this capital.

At the same time, while the three applications I described in this document were successful in helping individuals reflect on their past experiences and actions, they provided little support for action at the time of action. An example of such support can be found in one of my previous applications, Time Aura (Mamykina *et al.*, 2001), which used visual cues, such as changing colors to help individuals pace their activities. In contrast to CHAP, MAHI and Di-Tag, Time Aura provided assistance not only for reflection at quiet moments, but also, and primarily in the midst of action. I believe

exploration of similar approaches in management of chronic diseases can prove to be an interesting research area.

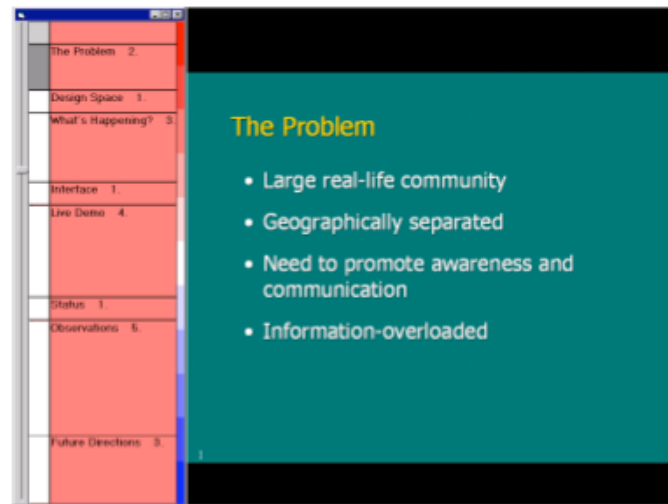


Figure 9: Time Aura.

APPENDIX A

HEALTH LOCUS OF CONTROL QUESTIONNAIRE

Name _____ Date _____

This questionnaire is designed to determine the way in which different people view certain important health-related issues. Each item is a belief statement with which you may agree or disagree. Beside each statement is a scale, which ranges from strongly disagree (1) to strongly agree (6). Please circle the number that represents the extent to which you disagree or agree with the statement. Please make sure that you answer every item and that you circle only one number per item. This is a measure of your personal beliefs; obviously there are no right or wrong answers.

Please answer these items carefully, but do not spend too much time on any one item. As much as you can, try to respond to each item independently when making your choice; do not be influenced by your previous choices. It is important that you respond according to your actual beliefs and not according to how you feel you should believe or how you think we want you to believe.

	Strongly Disagree	Moderately Disagree	Slightly Disagree	Slightly Agree	Moderately Agree	Strongly Agree
1. If I take care of myself, I can	1	2	3	4	5	6

avoid illness						
2. Good health is largely a matter of good fortune.	1	2	3	4	5	6
3. My family had a lot to do with my becoming sick or staying healthy	1	2	3	4	5	6
4. People who never get sick are just plain lucky	1	2	3	4	5	6
5. I can only do what my doctor tells me to do.	1	2	3	4	5	6
6. Whenever I get sick it is because of something I've done or not done	1	2	3	4	5	6
7. Having regular contact with my physician is the best way for me to avoid illness	1	2	3	4	5	6
8. People's ill health results from their own carelessness	1	2	3	4	5	6
9. No matter what I do, if I am going to get sick I will get sick	1	2	3	4	5	6
10. Most people do not realize the	1	2	3	4	5	6

extent to which their illnesses are controlled by accidental happenings						
11. When I feel ill, I know it is because I have not been getting the proper exercise or eating right	1	2	3	4	5	6
12. My health is dependent on how others treat me.	1	2	3	4	5	6
13. There are so many strange diseases around that you can never know how or when you might pick one up.	1	2	3	4	5	6
14. I am directly responsible for my health.	1	2	3	4	5	6
15. When I recover from an illness, it's usually because other people (for example, doctors, nurses, family, friends) have been taking good care of me.	1	2	3	4	5	6

APPENDIX B

DIABETES QUALITY OF LIFE QUESTIONNAIRE

Name _____

Date _____

Circle One

Pre-Test

Post-Test

This is a questionnaire designed to determine your view on how your diabetes affects your life. Each item is a belief statement with which you may agree or disagree. Beside each statement there is a scale. Please read each question and decide which choice best describes your attitude. Please indicate your answer by circling it. Please make sure that you answer every item and that you circle only one number per item. This is a measure of your personal beliefs; obviously there is no right or wrong answers. If you are not comfortable answering any of the questions for privacy reasons, please skip the question.

Please answer these items carefully, but do not spend too much time on any one item. As much as you can, try to respond to each item independently when making your choice; do not be influenced by your previous choices. It is important that you respond according to your actual beliefs and not according to how you feel you should believe or how you think we want you to believe.

1. How satisfied are you with your current diabetes treatment:

Very Satisfied	Moderately	Neither	Moderately	Very
	Satisfied		Dissatisfied	Dissatisfied

2. How satisfied are you with the amount of time it takes to manage your diabetes?

Very Satisfied	Moderately	Neither	Moderately	Very
	Satisfied		Dissatisfied	Dissatisfied

3. How often do you find that you eat something you shouldn't rather than tell someone that you have diabetes?

Never	Seldom	Sometimes	Often	All the time
-------	--------	-----------	-------	--------------

4. How often do you worry about whether you will miss work?

Never	Seldom	Sometimes	Often	All the time
-------	--------	-----------	-------	--------------

5. How satisfied are you with the time it takes to determine your sugar level?

Very Satisfied	Moderately	Neither	Moderately	Very
	Satisfied		Dissatisfied	Dissatisfied

6. How satisfied are you with the time you spend exercising?

Very Satisfied	Moderately	Neither	Moderately	Very
	Satisfied		Dissatisfied	Dissatisfied

7. How often do you have a bad night's sleep because of diabetes?

Never	Seldom	Sometimes	Often	All the time
-------	--------	-----------	-------	--------------

8. How satisfied are you with your sex life?

Very Satisfied	Moderately	Neither	Moderately	Very
	Satisfied		Dissatisfied	Dissatisfied

9. How often do you feel diabetes limits your career?

Never	Seldom	Sometimes	Often	All the time
-------	--------	-----------	-------	--------------

10. How often do you have pain because of the treatment for your diabetes?

- | | | | | | |
|--|-------|--------|-----------|-------|--------------|
| | Never | Seldom | Sometimes | Often | All the time |
|--|-------|--------|-----------|-------|--------------|
- 11.** How satisfied are you with the burden your diabetes is placing on your family?
- | | | | | |
|----------------|------------|---------|--------------|--------------|
| Very Satisfied | Moderately | Neither | Moderately | Very |
| | Satisfied | | Dissatisfied | Dissatisfied |
- 12.** How often do you feel physically ill?
- | | | | | |
|-------|--------|-----------|-------|--------------|
| Never | Seldom | Sometimes | Often | All the time |
|-------|--------|-----------|-------|--------------|
- 13.** How often do you worry about whether you will pass out?
- | | | | | |
|-------|--------|-----------|-------|--------------|
| Never | Seldom | Sometimes | Often | All the time |
|-------|--------|-----------|-------|--------------|
- 14.** How satisfied are you with the time spent getting checkups for your diabetes?
- | | | | | |
|----------------|------------|---------|--------------|--------------|
| Very Satisfied | Moderately | Neither | Moderately | Very |
| | Satisfied | | Dissatisfied | Dissatisfied |
- 15.** How satisfied are you with your knowledge about your diabetes?
- | | | | | |
|----------------|------------|---------|--------------|--------------|
| Very Satisfied | Moderately | Neither | Moderately | Very |
| | Satisfied | | Dissatisfied | Dissatisfied |

APPENDIX C

QUALITATIVE ANALYSIS: THE FINAL CODING SCHEME

Educator

1. Asking for clarification (follow-up questions):

The educator wants to make sure she understands the situation correctly.

Purpose

Clarifying Details ----- Inviting for Reflection

What was for dinner? VS What contributed to carbs in the salad?

Recurrence

Single incident ----- Ongoing practice

Is there an expectation that this issue should be clarified every time? E.g. “Please at your next post dinner or bedtime reading could you please send me summary of your dinner meals.”

Specificity

Specific occurrence ----- General

“What time was dinner?” vs. “How often do you...?”

2. Asking stand-alone questions

Purpose

Gathering information ----- Inviting for Reflection

What was for dinner? VS What contributed to carbs in the salad?

Specificity

Specific ----- Open-ended

“When you wake up do you feel rested?” vs. “How are you feeling?”

Reason

Concrete ----- Exploratory

Is the educator exploring possible explanations for something? E.g. “Have you changed your snack?”

3. Providing feedback

Object

Actions ---- Theories ----- Outcome

Anticipated change

Understanding -----Behavior

Specificity

Specific occurrence ----- General

“This number is within normal range.” vs. “Keep up the great efforts it will pay off.”

Emotional/encouragement

None ----- A lot

Is the feedback meant to validate a specific idea or encourage a specific behavior? E.g.

“Your observations are correct.”

Valence

Positive ----- Negative

4. Shaping understanding: Diabetes teaching

Context

Related to S's actions ----- Unrelated

Origins

Solicited ----- Unsolicited

Specificity

Specific ----- Generic

E.g., “I would not recommend Boost” VS “You need 30 g of carbs per meal”

Purpose

Internal ----- External

E.g., to justify a question or to shape understanding or behavior

Depth

Fundamental ----- Nuance

The statement is meant to provide a new understanding (“The high fructose corn syrup is not recognized by the muscles of the body”) vs. the statement is meant to expand an understanding the student has demonstrated (“toning and losing weight will improve your blood glucose levels by improving your insulin resistance.” – the student knows that exercise is good, but might not know why)

Technicality

Lay person ----- Medical

“you need a carbohydrates at each meal. “ vs. “The key is the carb/protein ratio. 10-20grams carb/7 grams protein.”

5. Providing information/answering questions (super-category)

6. Making recommendations

Method

Implicit ----- Explicit

The recommendation is made explicitly, or the recommendation is made in the context of, e.g., asking a question.

Valence

Positive ----- Negative

A recommendation *for* something vs. recommendation *against* something. (the educator is hesitant to use the later, but does in the end for the Boost shake.)

Novelty

First mention ----- Reaffirming

Is this the first time the educator is making this recommendation, or is she restating a previous recommendation?

7. Acknowledging student’s self-efficacy

Strength

Weakly ----- Strongly

“I will check out the site.” (i.e. Acknowledging validity of information the student may find) vs. “It sounds like a really good learning experience.” (i.e. Acknowledging that the student can learn on his own.)

Method

Implicit ----- Explicit

Effect

Closure ----- Follow-up question

Does the acknowledgement bring closure to a line of discussion (e.g. as with “Sounds like a perfect routine. Keep up the great effort. I will pay off.”)?

8. Indicating trends

Direction

Positive ----- Negative

9. Exchange tokens

Greetings

Commitments

Signatures

Acknowledgements

Student

1. Annotating automatically captured data (BG readings)

Media

Voice ---- Text ---- Image

Type

Routine ----- Remarkable

“Routine morning check.” vs. “This reading was taken after lunch”

Context

None ----- A lot

How much context is provided for the measurement? (What was eaten, when, etc.)

2. Providing information or answering question

Origins

Solicited (answer) ----- Unsolicited

Richness

Simple ----- Detailed

“4 hours after starting dinner.” vs. “about 2.5 hours after I started lunch; the lunch was a grilled chicken salad and a diet soda.”

Type

Experience ----- Theory

Relating to

Specific occurrence ----- Lifestyle

background

“I had dinner about 5:30” vs. “My morning BG levels often seem higher on the weekends.”

Contextual? Yes ----- No

Is the student contextualizing a BG reading?

Repeated? One-time ----- Response to standing

question

Is this, e.g., an answer to a request for clarification from the educator, or is this information the student provides routinely, e.g., dinner summary.

3. Stating current understanding

Source Own experience ----- External

information

External information could be unidentified (“I’ve heard that...”) or specific (McDonald’s website)

Abstractness Specific situation ---- ----- General understanding

“small order of fries (I know, bad)” vs. “I realize of course that one reading doesn’t mean anything”

Novelty New ----- Preexisting

Is this an understanding the student has learned from interacting with the educator, or something he knew from before?

Method Implicit ----- Explicit

Paul sometimes implies that he understands by, e.g. judging his actions (“I had probably more than I should have”)

Valence Positive ----- Negative

Is this knowledge about what the student *should* do or *shouldn't* do?

4. Soliciting advice:

<i>Domain</i>	Behaviors -----	Medicine
<i>Novelty</i>	First time -----	Asking for

reconfirmation

“Do you think I should be asking my doctor about Metformin” vs . “Please let me know if you would still not recommend it as a pre-bed snack.”

<i>Specificity</i>	Specific -----	General
--------------------	----------------	---------

5. Asking questions

<i>Domain</i>	Actions -----	Understanding
<i>Context</i>	Interaction through system -----	External interaction

Is the question about something the educator said, or about something he heard in class or from someone else?

<i>Method</i>	Implicit -----	Explicit
---------------	----------------	----------

“I don’t understand...” vs. “Does...?”

<i>Specificity</i>	Specific -----	General
--------------------	----------------	---------

6. Awaiting results of action/setting up next conversations

<i>Richness</i>	Simple -----	Detailed
<i>Certainty</i>	Specified -----	Open

“I will check back again tomorrow morning and will let you know what the results look like.” vs. “I'm hoping that as I continue to lose weight, the numbers will continue to drop.”

7. Showing appreciation

Strength

Weak ----- Strong

“Thank you, have a good night.” vs. “I do want to say that I have found this means of communications very useful - having immediate feedback and advice has proven to be much more helpful than I imagined that it was going to be (I will admit to having been very skeptical). Thank you.”

8. Voicing a problem

Source: feeling ----- outcome

Frequency: single ----- frequent

9. Sharing experience

Valence positive ----- negative

Specificity specific ----- generalized (I usually...)

Related to E's advice related ----- unrelated

Repeated repeated ----- singular

10. Exchange tokens

Greetings

Commitments

Signatures

Acknowledgements

11. Comments for MAHI

APPENDIX D

DESIGN: MAHI MOBILE

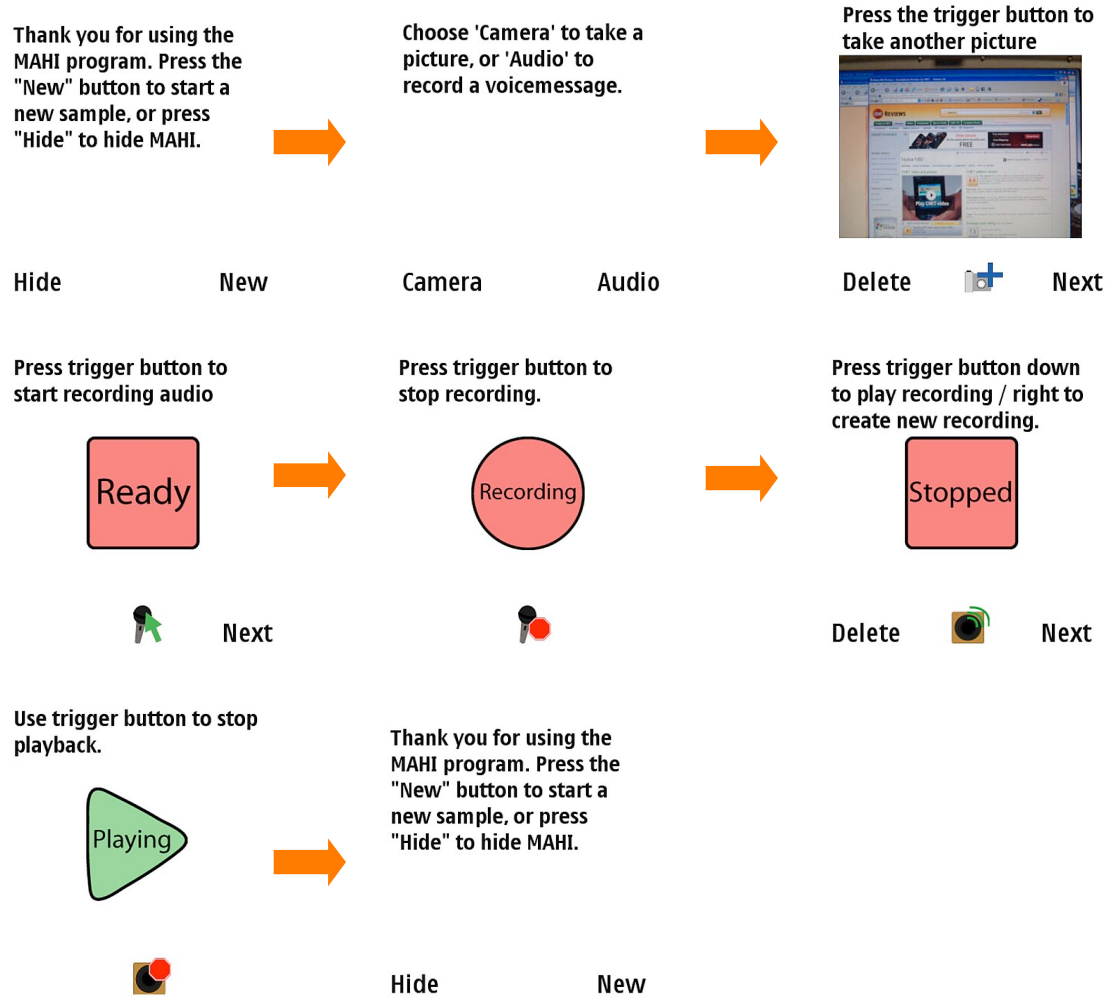


Figure 10: Selected screen shots of MAHI Mobile.

APPENDIX E

DESIGN: MAHI WEB

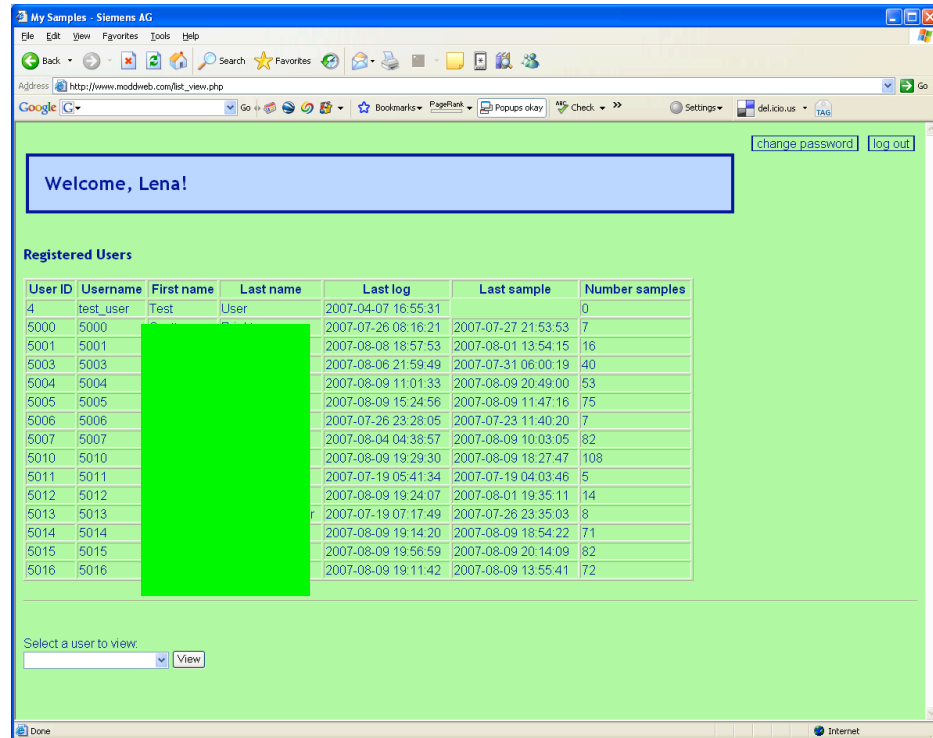


Figure 11: MAHI Web, researchers' view.

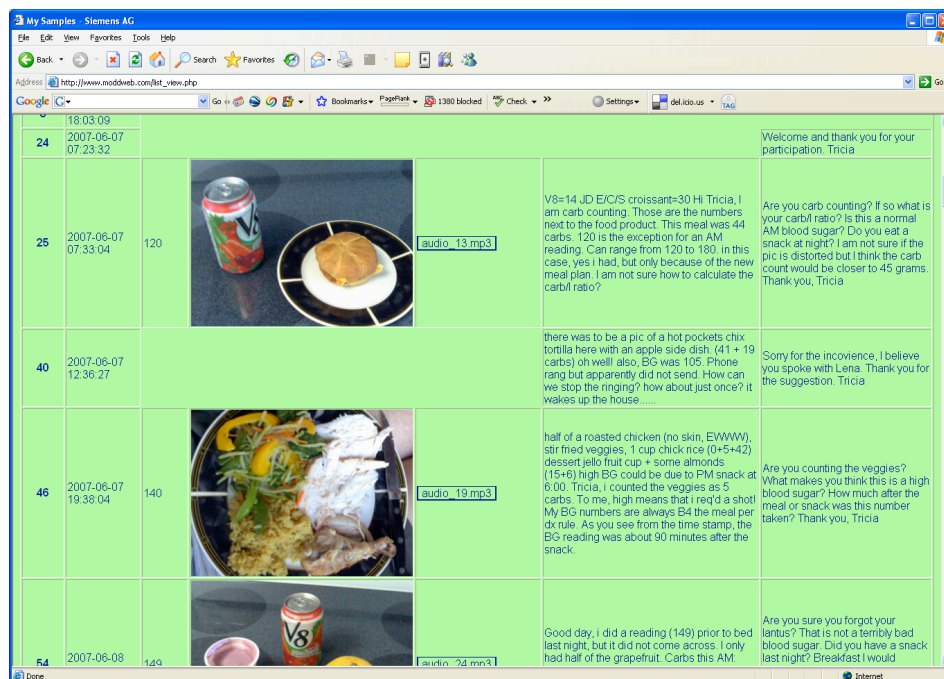


Figure 12: MAHI Web, participants' and care providers' view.

APPENDIX F

DESIGN: DI-TAG MOBILE

Thank you for using the MAHI program. Press the "New" button to start a new sample, or press "Hide" to hide MAHI.

Choose 'Camera' to take a picture, or 'Audio' to record a voicemail.

Press the trigger button to take another picture



Hide

New

Camera

Audio

Delete



Next

Thank you for using the MAHI program. Your 1 pictures and 0 audio notes will be uploaded shortly. Press the "New" button to start a new sample, or press "Hide" to hide MAHI.

It's time to enter your impact blood glucose value. Are you ready? Choose "Later" to be reminded in five minutes or "OK" to proceed.

Hide

New

Later

OK

Thank you for providing this information. Your data will be uploaded to ModdWeb shortly.

OK

Figure 13: Di-Tag Mobile.

APPENDIX G

DESIGN: DI-TAG WEB

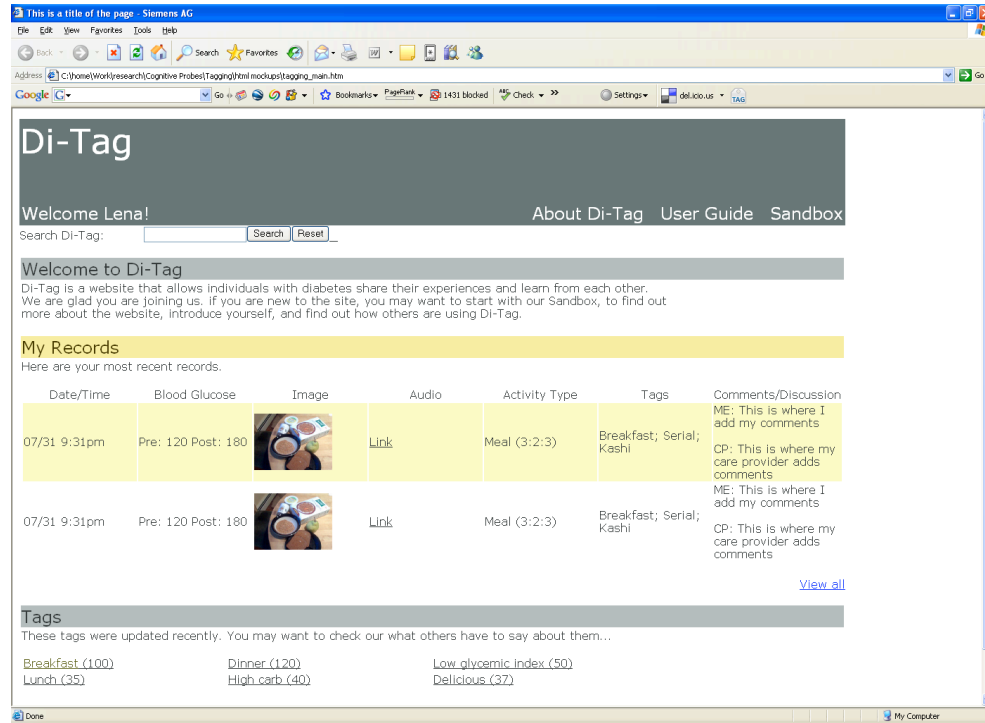


Figure 14: Di-Tag Web, intro screen.

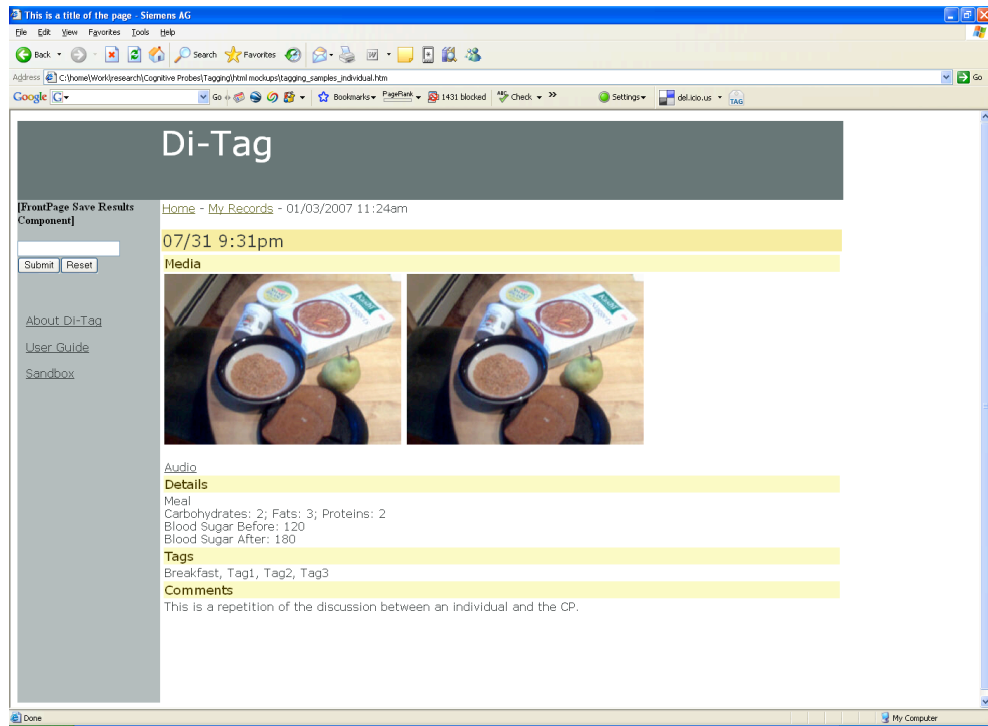


Figure 15: Di-Tag Web, record details.

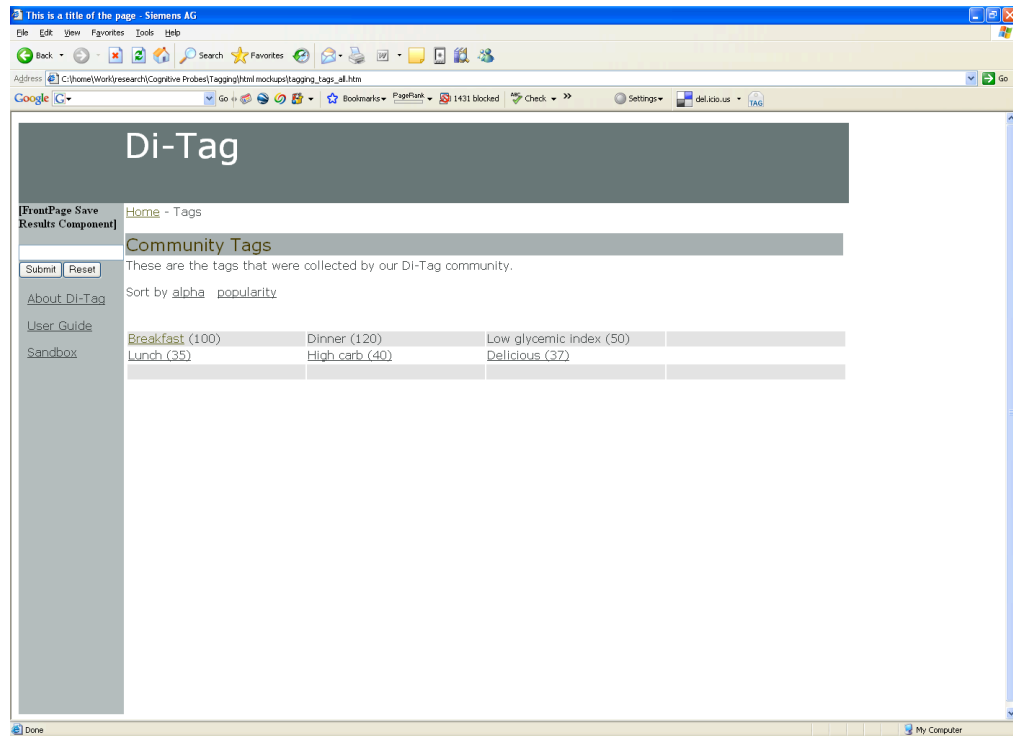


Figure 16: Di-Tag Web, tag library.

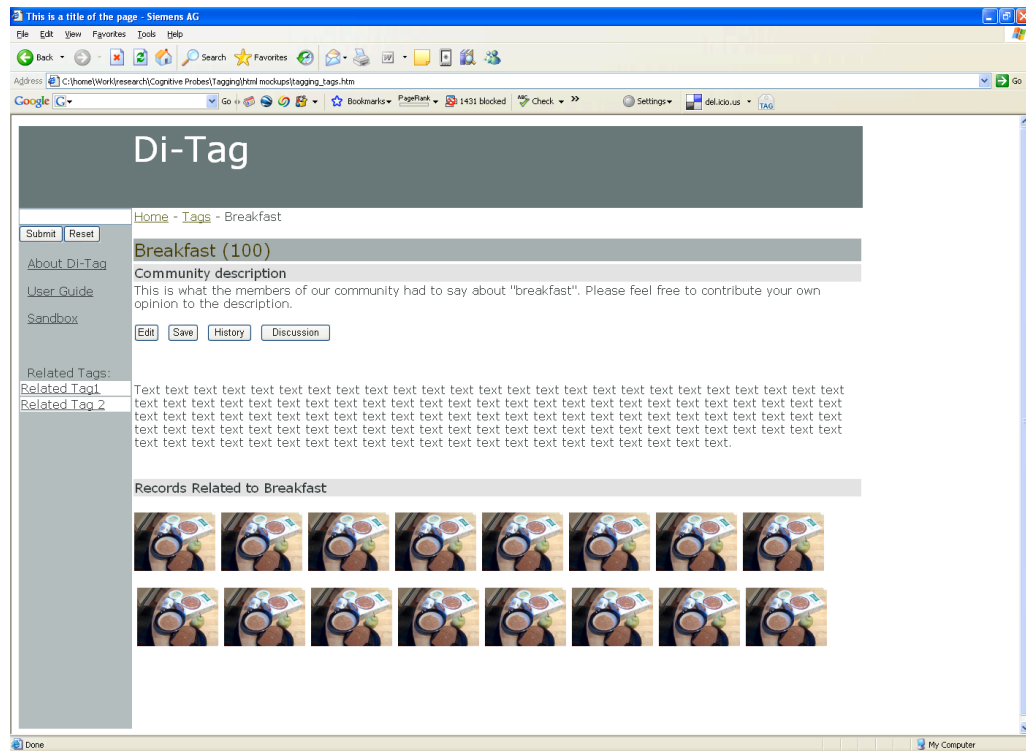


Figure 17: Di-Tag Web, single tag view.

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VITA

Lena Mamykina

MAMYKINA was born in Polyarny, Russia. She received a B.A. in Computer Science from the Ukrainian State University of Maritime Technology, Nikolayev, Ukraine in 1996, and a M.S. in Human-Computer Interaction from the Georgia Institute of Technology, Atlanta, GA in 2000. In 2005 she returned to Georgia Tech to pursue a doctorate in Human-Centered Computing. She currently resides in Atlanta, GA with her husband, Kliment and son, Max.